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**AN ECOSTRATIGRAPHIC STUDY OF
LATE PLEISTOCENE SEDIMENTS OF
THE WESTERN CHAMPLAIN SEA
BASIN, ONTARIO AND QUEBEC**

Cyril G. Rodrigues
S.H. Richard

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T.W. Anderson

Authors' Address

Cyril G. Rodrigues
Department of Geology
University of Windsor
Windsor, Ontario
N9B 3P4

S.H. Richard
Geological Survey of Canada
601 Booth St.
Ottawa, Ontario
K1A 0E8

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AN ECOSTRATIGRAPHIC STUDY OF LATE PLEISTOCENE SEDIMENTS OF THE WESTERN CHAMPLAIN SEA BASIN, ONTARIO AND QUEBEC

Abstract

Five marine pelecypod and cirriped associations, one freshwater pelecypod association, seven foraminiferal associations, and five groups of ostracode assemblages are recognized in Late Pleistocene sediments of the Thurso, Russell, Winchester, and Morrisburg map areas. Salinity and substrate are the primary factors controlling the distribution of macrofossils and microfossils. The *Balanus hameri*, *Macoma balthica*, *Portlandia arctica*, and *Cassidulina reniforme*-*Islandiella helenae*-*Haynesina orbicularis* associations characterize high salinity bottom water. The *Macoma balthica* and *Elphidium* sp.-*Haynesina orbicularis*-*Elphidium clavatum* associations and *Cytheromorpha macchesneyi*-dominant assemblages inhabited low salinity bottom water. *Cytheromorpha macchesneyi*-dominant assemblages are recurrent in the western Champlain Sea basin. The assemblages were present in the western part of the basin circa 11 800, 11 400, and 10 800 BP. Foraminifer diversity for 54 samples based on the Shannon-Wiener Information Function $[H(S)]$ ranged from 0.06 to 1.81 with a mean value of 1.02. Ostracode diversity $[H(S)]$ ranged from 0.00 to 1.77 in 14 samples that contained more than 100 valves. Foraminifer diversity does not appear to be influenced by salinity.

The successions of macrofaunal and foraminiferal associations are related, in part, to a change from high salinity (30 to 34‰) to lower salinity bottom water (10 to 30‰) from the base to the top of the successions. In the Navan area the transition from high to low salinity bottom water occurred between 11 000 and 10 800 BP.

The date of 10 200 ± 90 BP (GSC-3907, inner fraction) on *Hiatella arctica* from the top of a marine sequence near Bearbrook indicates that the *Hiatella arctica* association is not restricted to the early part of the Champlain Sea episode. The date of 11 800 ± 100 BP (GSC-3523) on *Macoma balthica* from a beach deposit near Merrickville provides an approximate age for deglaciation and marine submergence along the southwestern margin of the Champlain Sea basin.

Résumé

Cinq associations de pélecypodes et de cirripèdes marins, une association de pélecypodes d'eau douce, sept associations de foraminifères et cinq types d'assemblages d'ostracodes sont représentés dans la faune fossile des sédiments de la fin du Pléistocène de la région de Thurso, Russell, Winchester et Morrisburg. Les deux facteurs qui ont eu le plus d'influence sur la répartition des différentes espèces de la macrofaune et de la microfaune fossiles sont la salinité et la nature du substratum. Les associations de *Balanus hameri*, de *Macoma balthica*, de *Portlandia arctica*, et de *Cassidulina reniforme*-*Islandiella helenae*-*Haynesina orbicularis* ont vécu dans des eaux de fond à degré de salinité très élevé. Les associations de *Macoma balthica* et d'*Elphidium* sp.-*Haynesina orbicularis*-*Elphidium clavatum*, ainsi que les types d'assemblages où prédominaient *Cytheromorpha macchesneyi* vivaient, eux, dans des eaux de fond à degré de salinité très faible. Les assemblages d'ostracodes caractérisés par la présence d'un nombre prépondérant de spécimens de l'espèce *Cytheromorpha macchesneyi* sont apparus à plusieurs époques différentes dans la partie ouest du bassin de la mer de Champlain, soit il y a environ 11 800, 11 400 et 10 800 ans. L'analyse de 54 échantillons pour obtenir la diversité des foraminifères à l'aide de la fonction d'information de Shannon-Wiener $[H(S)]$ a donné des valeurs allant de 0,06 à 1,81 avec une valeur moyenne de 1,02. La diversité des ostracodes $[H(S)]$ obtenue par l'analyse de 14 échantillons qui contenaient plus de 100 valves a donné des valeurs allant de 0,00 à 1,77. La salinité ne semble pas avoir eu une influence directe sur la diversité des foraminifères.

Les changements de composition faunique observés dans les associations de la macrofaune et de foraminifères depuis la base jusqu'au sommet des coupes dans les dépôts marins de la région résultent en partie d'un changement du degré de salinité des eaux de fond qui est passé de haut (30 à 34‰) au début à plus faible (10 à 30‰) à la fin de la période de sédimentation. Dans la région de Navan, le changement affectant le degré de salinité des eaux de fond s'est produit entre 11 000 et 10 800 BP.

La date de 10 200 ± 90 BP (CGC-3907, fraction interne) obtenue à partir de coquilles de *Hiatella arctica* au sommet d'une coupe dans les sédiments marins près de Bearbrook démontre que l'association à *Hiatella arctica* n'est pas limitée à la première phase de la mer de Champlain. La date de 11 800 ± 100 BP (CGC-3523) obtenue à partir de coquilles de *Macoma balthica* trouvées dans un dépôt de plage près de Merrickville donne un âge approximatif pour la déglaciation et la submersion marine le long de la bordure sud-ouest du bassin de la mer de Champlain.

INTRODUCTION

Marine water flooded the Ottawa, St. Lawrence, and Champlain Lowlands during the final retreat of the Laurentide Ice Sheet from eastern North America, forming an arm of the Atlantic Ocean known as the Champlain Sea. The oldest radiocarbon dates for pelecypod shells from Champlain Sea deposits indicate that marine water invaded Ottawa Valley as early as $12\,800 \pm 220$ BP (GSC-1859; Richard, 1974), as far west as Massena, New York, in upper St. Lawrence Valley by $12\,000 \pm 200$ BP (Kirkland and Coates, 1977), and Champlain Valley of New York by $11\,900 \pm 120$ BP (GSC-2338; Cronin, 1979a). Karrow et al. (1975), Karrow (1981), and Clark and Karrow (1984) consider the $12\,800 \pm 220$ BP date to be "too old". Conversely, Gadd (1980) explained the early invasion of marine water into Ottawa valley circa $12\,800$ BP as a calving bay in the Laurentide Ice Sheet. Clark and Karrow (1984) reasoned that marine water entered the western part of the Champlain Sea basin later than $12\,100$ BP and proposed a "windowblind" style of ice-marginal retreat from upper St. Lawrence Valley in the south across Ottawa valley in the north. The marine episode ended about 10 000 years ago when the connection to the Atlantic Ocean was closed by isostatic rebound (Elson, 1969a).

Invertebrate macrofossils and microfossils are common in Champlain Sea deposits. This report discusses the distribution and stratigraphic significance of pelecypods, cirripeds, foraminifers, and ostracodes, and the depositional environment of Late Pleistocene sediments of the Thurso (31 G/11), Russell (31 G/6), Winchester (31 G/3), and Morrisburg (31 B/14) map areas. The study area is between 75°W and $75^\circ30'\text{W}$ and extends across the western Champlain Sea basin from $45^\circ45'\text{N}$ to St. Lawrence River in the south (Fig. 1). Faunal data from two dated sites adjacent to the study area (Fig. 1), the Val-des-Bois site northwest of the

Thurso map area (Richard, 1980) and the Merrickville site west of the Morrisburg map area, are presented and compared to faunal assemblages from the study area. Sample sites in the Thurso, Russell, Winchester, and Morrisburg map areas are shown in Figure 2; 34 samples from 36 sites were used in this study.

Acknowledgments

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PREVIOUS STUDIES

Invertebrate fauna

Golding (1922) concluded that the size of pelecypod shells is related to paleosalinity in the Champlain Sea basin. Elson (1969a,b) proposed an earlier, cold, deep water *Hiatella* (= *Hiatella arctica*) phase and a later, warmer, shallow water *Mya* (= *Mya arenaria*) phase for the Champlain Sea episode. Wagner (1970) illustrated marine invertebrates, mainly molluscs, from Champlain Sea deposits in Ontario and Quebec. Cronin (1977a) recognized a Transitional phase that predates the *Hiatella* phase in Champlain Valley on the basis of the ostracode fauna. Cronin (1979a) described a nearshore shallow water (less than 30 m) and an offshore deeper water (30 to 100 m) foraminiferal biofacies from deposits of the St. Lawrence Lowlands. The shallow water biofacies is characterized by congeners of *Elphidium* and *Haynesina orbicularis* (*Protelphidium orbiculare* of Cronin) and the



Figure 1. Location map of part of western Champlain Sea basin.

deeper water biofacies is characterized by *Cassidulina reniforme* (*C. crassa* of Cronin), *Islandiella helenae*, and *Elphidium clavatum* (*E. excavatum* forma *clavata* of Cronin). Cronin (1979b) discussed the variation in foraminifer and ostracode species diversity in samples from southeastern Ontario, southern Quebec, and Champlain Valley of New York and Vermont, using the Shannon-Wiener Information

Function $[H(S)]$. He reported that $H(S)$ averaged 1.5-1.7 in Ontario and Quebec, reaching as high as 2.5 in Ontario, whereas $H(S)$ averaged about 1.0 in Champlain Valley. Cronin concluded that the lower average diversity in Champlain Valley may signify a region of decreased salinity.

Hillaire-Marcel (1977, 1980) recognized six pelecypod communities (associations of this study) from Champlain Sea deposits in southern Quebec. He concluded that substrate and water mass properties are the major factors controlling the distribution of the communities. Corliss et al. (1982) described foraminiferal assemblages in two piston cores (M74-10 and M75-4) from Lake Champlain. They reported that *Cassidulina reniforme* and *Islandiella helenae* were the dominant foraminifers during the initial phase of the Champlain Sea and were replaced by *Elphidium clavatum* (*E. excavatum* forma *clavatum* of Corliss et al.) and *Haynesina orbicularis* (*Protelphidium orbiculare* of Corliss et al.) during the remainder of the sea's history. Also, they concluded, on the basis of isotopic and foraminiferal data, that nearly normal marine conditions were present during the initial phase of the Champlain Sea followed by decreasing salinity and increasing temperature as the sea evolved in Champlain Valley.

Rodrigues and Richard (1983) described seven marine pelecypod and cirriped associations and one freshwater pelecypod association from late glacial and postglacial sediments west of 74°W in the Ottawa-St. Lawrence Lowlands. They pointed out that the *Balanus hameri* or *Portlandia arctica* or *Hiatella arctica* association occurs at the base of the marine sequences and is replaced by the *Macoma balthica* or *Mya arenaria* or freshwater *Lampsilis* association at the top of the sequences. Rodrigues and Richard concluded that the successions are related to the changing physical and chemical properties of the bottom water and variations in the substrate. Rodrigues (1984) reported a succession from a freshwater *Candona* association to marine foraminiferal associations in cored sections from the deeper parts of the Champlain Sea basin in Ottawa Valley.

Late Pleistocene sediments

Coleman (1901a, b) described fossiliferous beach gravel and boulder clay from the Winchester and Morrisburg map areas. Owen (1951) produced the first detailed map of glacial and postglacial deposits of the Morrisburg and parts of the Winchester and Cornwall map areas. Chapman and Putnam (1966) discussed the Quaternary history of southern Ontario including the Ontario portion of the present study area. Gadd (1976) described Late Quaternary deposits and associated landslides of the southeastern part of the Thurso and the eastern part of the Russell map areas. Gadd (1977) recognized four sedimentary facies in the Ottawa Valley portion of the Champlain Sea basin on the basis of 27 cored sections, i.e., 1) a varved clay facies at the base, commonly overlying till, 2) a deepwater marine facies consisting of fossiliferous, dark blue-grey clay and silty clay, 3) a regularly banded, grey silty clay and red clay facies, and 4) an interbedded sand, silt, and clay facies at the top of the cores.

Vincent (1976) produced a preliminary map showing the surficial deposits of part of the Thurso map area. Richard et al. (1977) mapped the surficial deposits and terrain features of the Ottawa-Hull area which includes parts of the Winchester, Russell, and Thurso map areas. Recently, Richard (1982a-c) mapped the surficial geology of the Russell, Winchester, and Morrisburg map areas.

An extensive account of the Quaternary sediments of the Merrickville map area is presented in Sharpe (1979). Taylor (1979) described pelecypods and foraminifers from Champlain Sea deposits and the grain size characteristics of

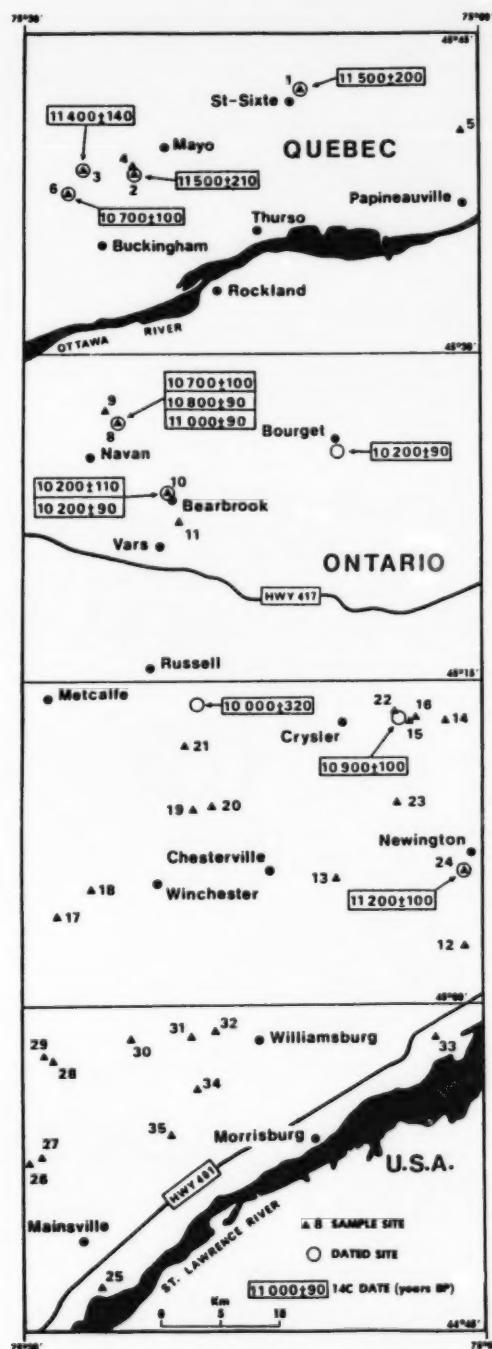


Figure 2. Sample sites in the Thurso, Russell, Winchester, and Morrisburg map areas.

glacial and marine deposits that are exposed in gravel and sand pits north of Buckingham in the Thurso map area. The distribution of Late Quaternary sediments and radiocarbon dates for pelecypods in late glacial and postglacial sediments of the Thurso and Low map areas were reported by Richard (1980). Poschmann et al. (1983) classified the landslide potential of riverbanks and slopes composed of postglacial clays in the Russell, Winchester, and Morrisburg map areas.

Richard (1975a) reported the occurrence of "fossiliferous till" in the Winchester map area. Shells of *Hiatella arctica* (Linné) from the till-like material near Newington yielded a radiocarbon date of $11\,200 \pm 100$ BP (GSC-2108; Richard, 1975b). Richard (1975b) pointed out that some of the shells in the till were broken and postulated that the "Newington ice lobe", which extended over the Prescott-Newington-Cornwall area, advanced into the Champlain Sea, scooped up the marine shells, and redistributed them throughout the glacial sediment. Furthermore, he suggested that the age obtained from shells in the till dates the post-Fort Covington ice readvance postulated by Terasmae (1965) in the Cornwall area.

Some workers have commented on the origin and significance of the till-like material. For example, Harrison (1977) concluded that the till-like material was formed by coastal processes in the Champlain Sea. Gadd (1977) reported that there is no evidence for the proposed readvance or for a significant hiatus in cored sections from Ottawa Valley. Dreimanis (1977) suggested that the "fossiliferous till" could be a wave-reworked and slumped exposure of the Fort Covington Till, containing marine shells admixed from younger, fossiliferous beach gravels. Fullerton (1980) discounted the glacial origin of the till-like material. He concluded that the material is a reworked deposit produced by waves, currents, and tides in the Champlain Sea. Hayward and French (1980) postulated that the till may be part of a kettle-fill sequence.

It is noteworthy that Coleman (1927, 1932) described interglacial marine sand and gravel with articulated pelecypod valves, overlain by stony till with broken pelecypod shells from the Cornwall map area, adjacent to the Newington site. According to Coleman (1927, p. 398), "... the ice must have scraped up part of the shell bearing gravel, mixing it with the other material it was carrying." However, on the basis of observations south of Cornwall in New York State, MacClintock and Stewart (1965) concluded that the fossiliferous stony till of Coleman (1932) was formed by waves and currents of the Champlain Sea washing out finer material of the till; they described the deposits as "winnowed till."

At the Newington site the till-like material with articulated valves and broken shells of *Hiatella arctica* and plates of *Balanus crenatus* Bruguière is overlain by gravel and sand containing *Macoma balthica* (Linné). A textural analysis reveals that the matrix of the till-like material consists of 45% sand, 38% silt, and 17% clay (P.J. Barnett, personal communication, 1981). The high proportion of silt and clay in the matrix does not support the winnowing hypothesis. Further study is required to ascertain the origin of the "fossiliferous tills" in southeastern Ontario.

METHODS

Samples were collected for microfaunal analysis from Late Pleistocene sediments exposed in gravel and sand pits, drainage ditches, roadcuts, and along river banks. At each site the lithology and macrofossils were recorded at the level sampled. In the laboratory the samples were air dried and a part of the dried sample was weighed and disaggregated by soaking in water. The slurry was washed by hand in running

water in a 63 μm sieve to remove the silt and clay fractions. After most of the silt and clay were washed out, the residue was cleaned ultrasonically, dried, weighed, and sieved using 850, 425, 250, 180, 150, and 75 μm sieves. Foraminifers and ostracodes were picked from each sieve fraction and mounted on standard 60-grid micropaleontological slides. The residue in some sieve fractions contained large numbers of microfossils and fairly large amounts of mineral grains and rock fragments. For those sieve fractions ostracode carapaces and valves were picked out and foraminiferal tests were concentrated by floatation. The sinks were examined and tests that did not float were picked out.

Carbon tetrachloride, density 1.6 g/cm^3 , is commonly used by some workers to separate empty foraminiferal tests from the residue. Buzas (1965) and Feyling-Hanssen (1976) pointed out that a greater number of empty tests are separated using a higher density liquid compared to the lighter carbon tetrachloride. In this study, a mixture of tetrabromoethane and acetone, density 1.9 g/cm^3 , was used to concentrate the tests. Most of the foraminiferal tests (greater than 95%) were separated from the residue using the tetrabromoethane-acetone mixture.

Foraminifer and ostracode diversities were computed using the Shannon-Wiener Information Function, $H(S) = -\sum p_i \ln p_i$, where $H(S)$ is the diversity, S is the number of species or taxa in the sample, p_i is the proportion of the i th species or taxon, and $\ln$ is the natural logarithm. Species proportions are taken into account, thereby minimizing the contribution of rare species. The minimum value of $H(S)$ is 0.00 for S equals to 1. The maximum value of $H(S)$ for a given S occurs when all S species are equally distributed.

Raw data comprising counts of foraminiferal taxa were processed by computer to obtain the per cent abundance of each taxon in the samples. The per cent abundances were used as input data for the Fortran program CLUSTER (Davis, 1973) that performs weighted pair group cluster analysis (WPGA) and arranges the samples into a hierarchical classification on the basis of the abundant taxa. Initially, similarities are computed between all possible sample pairs using the Pearson product moment correlation coefficient. Samples with the greatest similarities are grouped first and the other samples are grouped in subsequent iterations. Finally the results are displayed in a dendrogram. Sample groupings obtained from WPGA are based on the repeated occurrences of abundant taxa and are here designated associations. Each association is defined with respect to the dominant taxa that are characterized by mean abundances arbitrarily set at greater than 6%.

Plates 1, 2, and 4 to 6¹ were prepared from photomicrographs obtained by use of the SEMCO nanolab 7 scanning electron microscope. Plate 3 was prepared from photomicrographs obtained by reflected light using the Leitz Labrolux K microscope, Wild MPS 45 Photoautomat, and Polaroid camera attachment. The photographic equipment is housed at the University of Windsor. Illustrated specimens were deposited in the Paleontological collections of the Geological Survey of Canada (GSC), Ottawa, Ontario; GSC hypotype numbers for the illustrated specimens are given in the plate descriptions.

FAUNA

General

Macrofaunal, microfaunal, and lithologic data for the samples are listed in Table 1 and the locations of samples sites are shown in Figures 1 and 2. Six of the eight macrofaunal associations recognized by Rodrigues and Richard (1983) for the western Champlain Sea basin are present in the study area, i.e., the freshwater *Lampsilis*

¹For Plates see pages 22 through to 33

association, and the marine *Balanus hameri*, *Hiatella arctica*, *Macoma balthica*, *Mytilus edulis*, and *Portlandia arctica* associations. *Mya arenaria* Linné was not observed in the study area. The western limit of *M. arenaria* is in the Alexandria and Cornwall map areas (Rodrigues and Richard, 1983). *Mya truncata* Linné s. l. was observed only in the Russell map area at Sites 10 and 11.

Fifty-three calcareous benthonic foraminiferal taxa were identified and 61 972 specimens were counted from 54 samples used in this study. The number of specimens per assemblage ranges from 119 to 3747, the number of taxa per assemblage ranges from 2 to 27, and foraminifer diversity [H(S)] ranges from 0.06 to 1.81. The genera *Buliminella* Cushman, *Cyclogyra* Wood, *Entolingulina* Loeblich and

Tappan, *Glabratella* Dorreen, *Parafissurina* Parr, and *Pseudoparrella* Cushman and ten Dam are reported for the first time from the western Champlain Sea basin. Also, the species *Buccella calida* (Cushman and Cole) (Pl. 1, fig. 15), *Cyclogyra involvens* (Reuss), *Entolingulina translucida* (Heron-Allen and Earland) (Pl. 3, fig. 3), *Fissurina reniformis* (Sidebottom) (Pl. 1, fig. 9; Pl. 3, fig. 11), *Parafissurina fusuliformis* Loeblich and Tappan, and *Pseudoparrella takayanagii* (Iwasa) were not previously reported from the western Champlain Sea basin.

In general the generic assignments of the foraminifers conform with those of Loeblich and Tappan (1964). The taxonomy of *Pseudoparrella* follows that outlined by Lipps (1965). *Dentalina ittai* Loeblich and Tappan is

Table 1. Macrofaunal, microfaunal, and lithologic data for samples

Map Area	Site Number	Sample Number	Elevation (m a.s.l.)	Lithology	Macrofaunal Association	Weight of Sediment Processed (g)	Foraminifera			Ostracoda		
							Number of Tests	Number of Taxa	Diversity [H(S)]	Number of Valves	Number of Taxa	Diversity [H(S)]
Thurso (31 G/11)	1	1	144	Clay	<i>Portlandia arctica</i>	100.0	119	4	0.21	36	1	
	2	2	182	Clay	^a HA-MB	75.0	282	3	0.61	1	1	
	3	3	180	Pebbly sandy clay	<i>Hiatella arctica</i>	75.0	225	4	0.74	63	3	
	4	4	168	Clayey sand	<i>Macoma balthica</i>	101.1	427	5	0.79	14	3	
	5	5	151	Pebbly sandy clay	<i>Hiatella arctica</i>	25.0	637	7	0.98	19	4	
	6	6	146	Pebbly sandy clay	<i>Hiatella arctica</i>	25.0	753	10	0.88	2	1	
Low (31 G/13)	7	7	180	Clayey sand	<i>Macoma balthica</i>	100.0	149	4	1.08	113	1	0.00
Russell (31 G/6)	8	8A	95	Pebbly sandy clay	<i>Balanus hameri</i>	27.5	2495	27	1.45	10	3	
		8B		Pebbly clayey sand	<i>Hiatella arctica</i>	26.0	754	20	1.81	410	12	1.77
		8C		Pebbly sandy clay	<i>Hiatella arctica</i>	26.0	1024	17	1.58	314	10	1.63
		8D		Pebbly sandy clay	<i>Hiatella arctica</i>	26.0	1588	20	1.46	176	10	1.56
		8E		Sandy clay	<i>Hiatella arctica</i>	26.0	1867	17	1.44	513	12	1.62
		8F	94	Sandy clay	<i>Hiatella arctica</i>	26.0	2041	14	1.47	688	10	1.52
		8G		Sandy clay	<i>Hiatella arctica</i>	26.0	2570	16	0.85	311	8	1.66
		8H		Clay	<i>Hiatella arctica</i>	26.0	1261	14	0.71	161	6	1.42
		8I		Clay	<i>Hiatella arctica</i>	26.0	2057	14	0.74	224	6	1.20
		8J		Clay	<i>Mytilus edulis</i>	101.0	386	6	1.04	39	5	
		8K		Sand	<i>Macoma balthica</i>	26.0	391	12	1.57	55	7	
		8L	93	Sand	<i>Macoma balthica</i>	26.0	776	13	1.28	115	8	1.23
	9	9	91	Pebbly clayey sand	<i>Hiatella arctica</i>	50.0	287	14	1.49	88	9	
	10	10A	69	Sandy clay	<i>Hiatella arctica</i>	25.0	2773	15	1.19	115	5	1.08
Winchester (31 G/3)		10B		Clayey sand	<i>Hiatella arctica</i>	25.0	630	10	1.01	84	5	
		11A	76	Pebbly clayey sand	<i>Balanus hameri</i>	25.0	761	18	1.57	7	3	
	11	11B		Clayey sand	<i>Hiatella arctica</i>	25.0	316	8	1.07	4	2	
	12	12	91	Pebbly sand	<i>Hiatella arctica</i>	26.0	801	10	0.79	-	-	
	13	13A	83	Pebbly clayey sand	<i>Hiatella arctica</i>	26.2	1301	18	1.26	18	5	
		13B		Pebbly sand	<i>Macoma balthica</i>	25.2	344	4	0.14	-	-	
	14	14	83	Clay	<i>Portlandia arctica</i>	25.3	3747	25	1.41	11	3	
	15	15	70	Clayey sand	<i>Macoma balthica</i>	25.3	1020	10	0.64	1	1	
	16	16	69	Clay	<i>Macoma balthica</i>	26.0	657	16	1.38	1	1	
	17	17	78	Clay	<i>Portlandia arctica</i>	26.7	1411	12	0.86	30	5	
	18	18	76	Clay	<i>Portlandia arctica</i>	25.4	2220	15	1.20	5	2	
	19	19	75	Clay	<i>Portlandia arctica</i>	27.1	1718	13	0.82	11	4	
	20	20	84	Pebbly clayey sand	<i>Hiatella arctica</i>	25.0	2385	15	1.24	82	5	
	21	21	69	Clay	<i>Portlandia arctica</i>	25.2	1395	20	1.27	37	9	
Morrisburg (31 B/14)		22A	73	Pebbly sandy clay	<i>Balanus hameri</i>	25.0	2186	18	1.37	8	3	
		22B		Sandy clay	<i>Hiatella arctica</i>	25.0	914	16	1.00	43	5	
		22C		Sandy clay	<i>Macoma balthica</i>	25.0	1353	11	0.82	4	3	
		22D	72	Sandy clay	-	26.0	1064	14	0.76	6	5	
		22E		Sandy clay	-	26.0	767	11	1.03	1	1	
	23	23	75	Sandy clay	<i>Macoma balthica</i>	26.0	980	15	1.21	4	2	
	24	24	106	Diamicton	<i>Hiatella arctica</i>	52.8	365	17	1.54	36	8	
	25	25	85	Clay	<i>Portlandia arctica</i>	100.5	1518	3	0.06	26	4	
	26	26	85	Clay	<i>Portlandia arctica</i>	104.1	270	4	0.42	127	3	0.75
	27	27	85	Clay	-	100.0	816	6	0.52	3	2	
	28	28	84	Sandy clay	<i>Macoma balthica</i>	30.0	2622	9	1.10	134	8	1.03
	29	29	83	Clay	<i>Portlandia arctica</i>	100.4	1294	5	1.38	15	5	
	30	30	75	Clay	<i>Portlandia arctica</i>	100.5	229	5	0.80	24	4	
Merrickville (31 B/13)	31	31	75	Clay	-	25.0	2996	7	0.82	^b 185	4	0.59
	32	32	81	Clayey sand	<i>Hiatella arctica</i>	21.0	1442	8	0.78	1	1	
	33	33	82	Sand	<i>Hiatella arctica</i>	50.3	515	8	1.12	7	3	
	34	34	85	Pebbly sand	<i>Macoma balthica</i>	31.7	466	6	1.05	8	3	
	35	35	79	Clay	<i>Portlandia arctica</i>	100.0	148	5	1.17	2	2	
	36	36	118-120	Clayey sand	<i>Macoma balthica</i>	49.9	459	2	0.14	60	4	

¹Alphabetic notations are for samples from different levels at a site.

²Elevations are interpreted from 1:50 000 topographic maps generally with a contour interval of 25 feet.

³Elevations are not given for samples that are less than 1 m of the lowest sample at a site.

⁴Diversities are listed for samples containing more than 100 valves.

⁵HA, *Hiatella arctica*; MB, *Macoma balthica*. The species are equally abundant at the level sampled.

⁶Macrofossils were not observed at the level sampled.

⁷Count is from 100.0 g of sediment.

tentatively assigned to *Dentalina* Risso. The species lacks the radiate aperture of *Dentalina* and is characterized by an entosolenian tube projecting into the final chamber (Pl. 3, fig. 7); it should be assigned to a new genus. Some generic and specific names used by Cronin (1979a) in his study of Late Pleistocene benthonic foraminifers from the St. Lawrence Lowlands were changed as follows: *Cassidulina crassa* = *Cassidulina reniforme* Nørvang (Rodrigues et al., 1980); *Elphidium excavatum* forma *clavata* = *Elphidium clavatum* Cushman (Rodrigues and Hooper, 1982a); *Eoeponidella laeoeensis* = *Eoeponidella pulchella* (Parker); *Protelphidium orbiculare* = *Haynesina orbicularis* (Brady) (Banner and Culver, 1978); *Trifarina fluens* = *Trifarina hughesi* (Galloway and Wissler) (Rodrigues and Hooper, 1982b); and *Virgulina loeblichii* = *Fursenkoina loeblichii* (Feyling-Hanssen) (Rodrigues and Hooper, 1982b). Taxa of the foraminiferal Family Polymorphinidae are grouped under Polymorphinid; *Elphidium incertum* (Williamson) and *E. asklundi* Brotzen are grouped as one taxon *E. incertum/asklundi*.

Ostracodes are not as abundant as foraminifers in the samples used in this study. Fifty-two samples yielded 4457 valves and 25 taxa. Fourteen samples contained more than 100 valves. For those samples the number of taxa ranges from 1 to 12 and diversity $[H(S)]$ ranges from 0.00 to 1.77. The genus *Argilloecia* Sars is reported for the first time from the western Champlain Sea basin. Cronin (1977a-b, 1981) assigned *Cythere bradleyi* Norman, *Cythereidea macrolaminata* Eloffson, and *Cythereidea punctillata* Brady to *Eucythereidea* Bronstein. We have followed Athersuch (1982) and referred the species to *Sarsicythereidea*.

Thurso

The *Hiatella arctica*, *Macoma balthica*, and *Portlandia arctica* associations, *Elphidium clavatum*-dominant and *Haynesina orbicularis*-dominant foraminiferal assemblages, diversity 0.21 to 0.88, are recognized for the six Thurso samples. The foraminiferal assemblage from the Val-des-Bois site of Richard (1980), *Elphidium* sp.-dominant (Pl. 2, fig. 13, 14), is distinctly different from the assemblages in the Thurso area. Also, the Val-des-Bois sample (7) yielded a higher foraminifer diversity (1.08) by comparison with the Thurso samples (Table 1). Two Thurso samples (1 and 3) and the Val-des-Bois sample contained more than 35 ostracode valves. *Cytheromorpha macchesneyi* (Brady and Crosskey) is the dominant species in samples 3 and 7; *Cytheropteron pseudomontrosiense* Whatley and Masson is the dominant species in sample 1.

Russell

The *Balanus hameri*, *Hiatella arctica*, *Macoma balthica*, *Mytilus edulis*, and *Lampsilis* associations are present in the Russell area. At Site 8 a succession from the *Balanus hameri* to the *Macoma balthica* association was observed in a gravel and sand pit about 3.5 km northeast of Navan. A plot of per cent abundances of dominant foraminiferal taxa from different levels of the marine sequence reveals four distinct ecozones (Fig. 3). The ecozones represent a succession from *Cassidulina reniforme*-dominant (Ecozone FA) to *Elphidium clavatum*-*Haynesina orbicularis*-*Elphidium incertum/asklundi*-dominant (Ecozone FB) to *Elphidium clavatum*-dominant (Ecozone FC) to *Elphidium* sp.-dominant assemblages

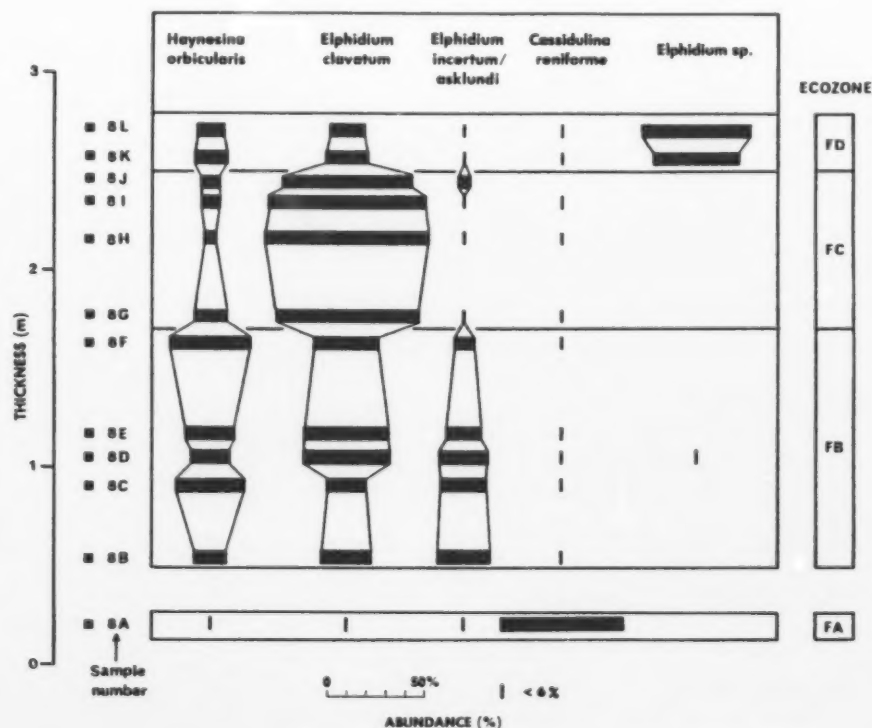


Figure 3. Relative abundance of dominant benthonic foraminiferal taxa from Site 8 near Navan, Ontario.

(Ecozone FD). Foraminifer diversity ranges from 1.44 to 1.81 in Ecozones FA and FB, decreasing to as low as 0.71 in Ecozone FC, and increasing to as high as 1.57 in Ecozone FD.

Ostracodes are common in most of the samples from Site 8 (Table 1). Two ostracode ecozones are recognized above the interval of the *Balanus hameri* association (Fig. 4). *Cytheropteron latissimum* (Norman) and *Sarsicytheridea*

punctillata (Brady) are abundant in Ecozone OA. *Cytheropteron nodosum* Brady is common in the lower part of Ecozone OA and rare to absent in the upper part of the ecozone. Conversely, *Sarsicytheridea bradleyi* (Norman) is absent in the lower part of Ecozone OA and common in the upper part of the ecozone. *Cytheromorpha macchesneyi*-dominant assemblages characterize Ecozone OB at the top of

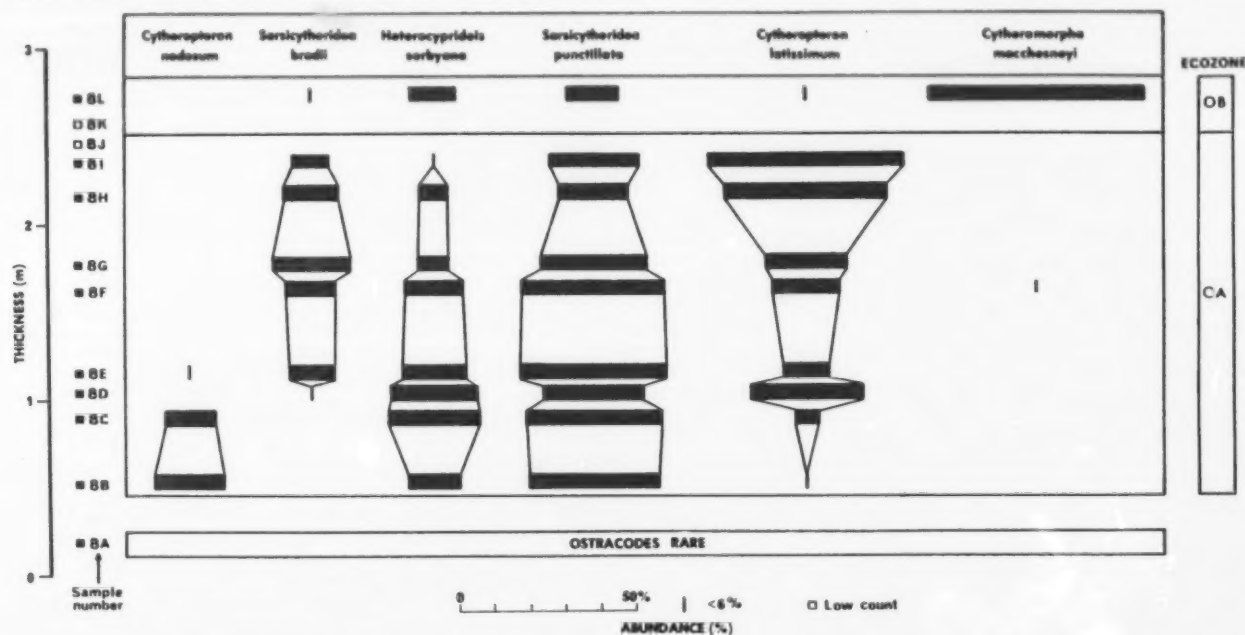


Figure 4. Relative abundance of dominant ostracode taxa from Site 8 near Navan, Ontario.

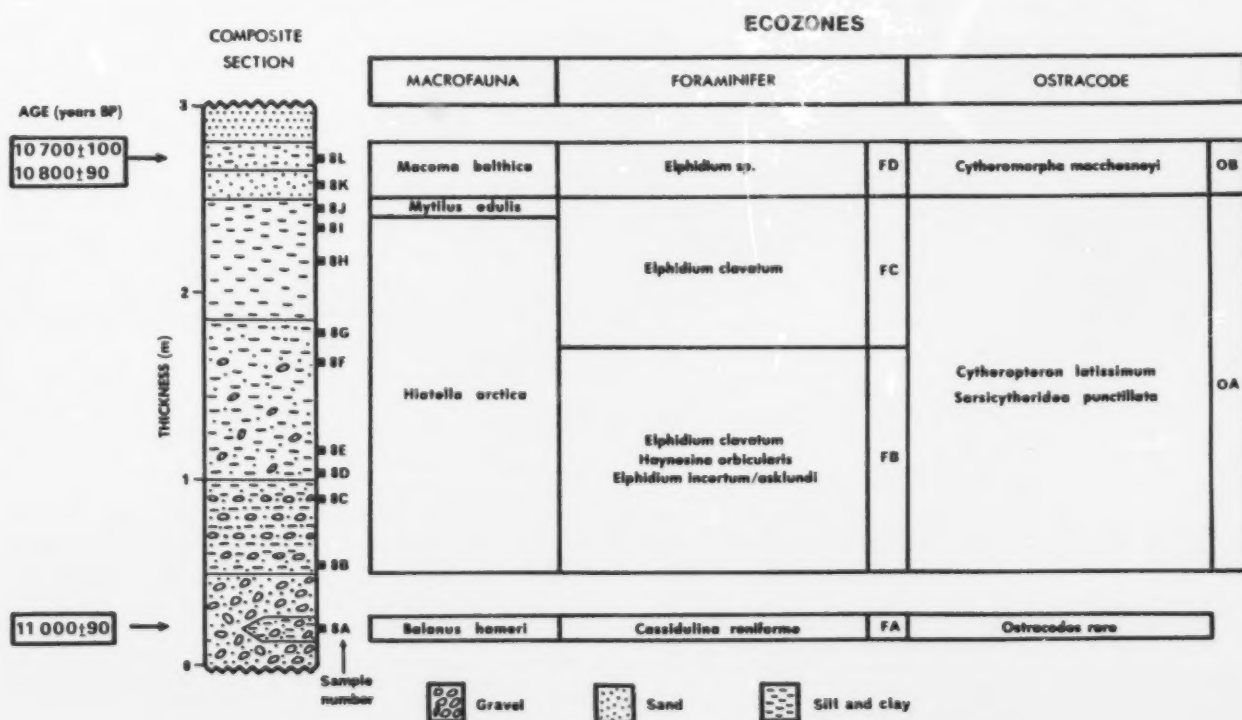


Figure 5. Ecozones and radiocarbon dates for a fossiliferous sequence at Site 8.

the section. Lithologic units, ecozones, and radiocarbon dates for the marine sequence at Site 8 are shown in Figure 5.

Sample 9 was collected about 1.2 km northwest of Site 8 from a shell bed containing the *Hiatella arctica* association. The foraminiferal assemblage, *Elphidium incertum*/*askundi*-*Elphidium clavatum*-*Haynesina orbicularis*-dominant, diversity 1.49, is comparable to the assemblages comprising Ecozone FB at Site 8. Also, the high numbers of *Sarsicytheridea punctillata* and *Cytheropteron nodosum* and the absence of *S. bradleyi* indicate that the ostracode assemblage is similar to that from the lower part of Ecozone OA at Site 8.

Site 10 is located about 0.5 km northwest of Bearbrook. Sample 10A was collected from a sandy clay horizon 1 m below the surface and sample 10B is from a shell bed 0.2 m below the surface. The *Hiatella arctica* association is characteristic of the levels sampled. *Macoma balthica*, *M. calcarea* (Gmelin), *Mya truncata* s.l., *Mytilus edulis* Linné, and *Portlandia arctica* (Gray) are present in the shell bed. *Astarte montagui* (Dillwyn) s.l., *Mytilus edulis*, *Neptunea despecta tornata* (Gould), and *Tethya logani* Dawson are present at the level of Sample 10B. Site 10 is the farthest west occurrence of *Mya truncata* (Rodrigues and Richard, 1983). *Elphidium clavatum* and *Haynesina orbicularis* are the dominant foraminifers, and *Sarsicytheridea punctillata* and *Heterocyprideis sorbyana* (Jones) are the dominant ostracodes in both samples from Site 10.

Site 11 is located about 2 km southeast of Bearbrook. Sample 11A is from a pebbly sandy clay containing the *Balanus hameri* association and sample 11B is from a shell bed overlying the pebbly sandy clay. *Astarte montagui* s.l., *Macoma balthica*, *Mya truncata* s.l., *Mytilus edulis*, *Neptunea despecta tornata*, *Tethya logani*, and small gastropods are present in the shell bed. A *Cassidulina reniforme*-dominant foraminiferal assemblage, diversity 1.58, from the interval of the *Balanus hameri* association is replaced by a *Haynesina orbicularis*-dominant assemblage, diversity 1.07, in the shell bed. Ostracodes are rare in the samples from Site 11.

Winchester

The *Balanus hameri*, *Hiatella arctica*, *Macoma balthica*, *Mytilus edulis*, and *Portlandia arctica* associations, *Haynesina orbicularis*-dominant, *Haynesina orbicularis*-*Cassidulina reniforme*-dominant, and *Cassidulina reniforme*-dominant foraminiferal assemblages are recognized in the Winchester area. Foraminifer diversity ranges from 0.14 to 1.54. Samples 20, 21, 22B, and 24 contained more than 35 ostracode valves. *Heterocyprideis sorbyana* and *Sarsicytheridea punctillata* are common in the samples. Sample 24 from the "fossiliferous till" at the dated Newington site of Richard (1975b) yielded a *Haynesina orbicularis*-*Cassidulina reniforme*-dominant foraminiferal assemblage and an ostracode assemblage characterized by *Baffinicythere emarginata* (Sars).

Site 22 is located in an abandoned gravel and sand pit about 400 m north of the Chrysler site of Richard in Lowdon and Blake (1980). A date of $10\,900 \pm 100$ BP (GSC-2614) was obtained for shells of *Macoma* spp. from the Chrysler site. In one part of the pit, pebbly clayey sand containing the *Balanus hameri* association is overlain by sandy clay containing the *Hiatella arctica* association. A *Cassidulina reniforme*-dominant assemblage (sample 22A) from the interval of the *Balanus hameri* association is replaced by a *Haynesina orbicularis*-dominant assemblage (sample 22B) from the interval of the *Hiatella arctica* association. A succession

from the *Balanus hameri* to *Hiatella arctica* association also accompanies a succession from a *Cassidulina reniforme*-dominant to *Haynesina orbicularis*-dominant assemblage at Site 11 in the Russell map area.

In another part of the pit at Site 22 sandy clay containing the *Macoma balthica* association is overlain by crossbedded sand and horizontally bedded gravel and sand. Clasts of sandy clay are present at the base of the crossbedded sand and in the gravel and sand. Samples (22C) from the fossiliferous sandy clay and from the clasts in the overlying beds (22D and 22E) yielded *Cassidulina reniforme*-dominant assemblages. Thus, the clasts in the crossbedded sand and horizontally bedded gravel and sand were probably reworked from the underlying fossiliferous sandy clay. Disarticulated valves of *Macoma balthica* are oriented convex upwards in the gravel and sand; they may have originated from the underlying fossiliferous sandy clay or from a higher elevation.

Morrisburg

The *Hiatella arctica*, *Macoma balthica*, and *Portlandia arctica* associations, *Elphidium clavatum*-dominant, *Elphidium clavatum*-*Cassidulina reniforme*-dominant, *Haynesina orbicularis*-dominant, and *Elphidium* sp.-*Haynesina orbicularis*-dominant foraminiferal assemblages are present in the Morrisburg area. Foraminifer diversity ranges from 0.06 to 1.38. Samples 26, 28, and 31 contained more than 100 ostracode valves. *Cytheropteron pseudomontrosiense* is abundant in samples 26 and 31; *Cytheromorpha macchesneyi* is abundant in sample 28. The sample (36) collected from the dated level at the Merrickville site is characterized by the *Macoma balthica* association, *Elphidium clavatum*-dominant foraminiferal and *Cytheromorpha macchesneyi*-dominant ostracode assemblages.

RADIOCARBON DATES

Some of the samples used in this study are from dated sites (Fig. 1, 2; Table 2). The significance of some of the dates is presented here. Plates of *Balanus hameri* (Ascanius) from the base of the fossiliferous sequence at Site 8 (Fig. 5) yielded a date of $11\,000 \pm 90$ BP (GSC-3706; Blake, 1984). Dates of $10\,800 \pm 90$ and $10\,700 \pm 100$ BP (GSC-3743), inner and outer fractions, respectively, were obtained for shells of *Macoma balthica* from the top of the sequence at Site 8. The dates for *M. balthica* are older than the Bourget date of $10\,200 \pm 90$ BP (GSC-1968; Lowdon and Blake, 1976) for freshwater *Lampsilis* shells that were collected about 42 m below the top of the marine sequence at Site 8.

The oldest dates from the western Champlain Sea basin are for shells of *M. balthica* from beach deposits near Clayton, White Lake, and Cantley (Fig. 1). Dates of $12\,800 \pm 220$ BP (GSC-1859; Richard, 1974), $12\,800 \pm 100$ and $12\,700 \pm 100$ BP (GSC-2151; Richard, 1978), outer and inner fractions, respectively, were reported for the shells from the Clayton site. A date of $12\,200 \pm 160$ BP (GSC-1646; Lowdon and Blake, 1973) was reported for shells from the Cantley site. Rodrigues and Richard (1983) reported dates of $12\,100 \pm 100$ (outer fraction), $12\,200 \pm 100$ (middle fraction), and $12\,100 \pm 100$ BP (inner fraction, GSC-3110) for shells from the White Lake site. Thus, it appears that the oldest record of marine sediments at Site 8 postdates marine inundation of the Ottawa valley region by 1200 to 1800 years.

Dates of $10\,200 \pm 90$ and $10\,200 \pm 110$ BP (GSC-3907), inner and outer fractions, respectively, were obtained for shells of *Hiatella arctica* from a shell bed at the top of the fossiliferous sequence at Site 10 about 0.5 km northwest of Bearbrook. The dates overlap with the Russell date of

10 000 $\pm$ 320 BP (GSC-1553; Lowdon and Blake, 1973) for shells of *Macoma* spp. from a beach deposit at an elevation of 70 m (Fig. 2). The Bearbrook dates for marine shells from an elevation of 69 m are almost identical to the Bourget date of 10 200 $\pm$ 90 BP (GSC-1968; Lowdon and Blake, 1976) for freshwater *Lampsilis* shells from an elevation of 53 m. Thus, the date for the freshwater shells appears to be too old compared to the dates for marine shells from the upper part of the marine sequence at the Bearbrook site. Alternatively, the freshwater shells at Bourget may be reworked from a higher elevation and the date of 10 200 $\pm$ 90 BP for the freshwater shells may not be too old.

Shells of *Macoma balthica* from a beach deposit at Site 36 at an elevation of 118 to 120 m and 4.5 km southeast of Merrickville yielded a date of 11 800 $\pm$ 100 BP (GSC-3523; Blake, 1984). The date corresponds closely to the Maitland date of 11 800 $\pm$ 210 BP (GSC-1013; Lowdon and Blake, 1970) for shells of *M. balthica* from a beach deposit near marine limit at an elevation of 103 m and 23 km south of Merrickville. The Merrickville date gives a minimum age for the deglaciation and marine submergence along the southwestern margin of the Champlain Sea basin in the Smiths Falls-Brockville area.

FORAMINIFERAL ASSOCIATIONS

The foraminiferal assemblages described above are based on visual inspection of per cent abundance data of foraminiferal taxa comprising the samples. The logical next

step was to arrange the samples into groups that could be used to document the lateral and temporal variations in the depositional environment of the late glacial and postglacial marine sediments. Weighted pair group cluster analysis of 54 samples yielded 7 distinct clusters of samples; each cluster defines one foraminiferal association (Fig. 6). The dominant taxa of the associations and their mean abundances are listed in Table 3. The taxa present in each association are listed in Table 4.

Association 1, *Elphidium clavatum*-*Haynesina orbicularis*-dominant, is present at the dated Merrickville site and in the Thurso, Russell, and Morrisburg map areas. Foraminifer diversity ranges from 0.06 to 1.19 and the mean diversity of 0.65 is the lowest for the associations described here. The *Elphidium* sp.-*Haynesina orbicularis*-*Elphidium clavatum* association (No. 2) occurs at the dated Val-des-Bois site and in the Russell and Morrisburg map areas. Foraminifer diversity ranges from 1.05 to 1.57 in Association 2 and is generally higher than in Association 1. Association 3, *Haynesina orbicularis*-*Elphidium clavatum*-dominant, occurs throughout the study area. The range of foraminifer diversity of Association 3 (0.14 to 1.47) is comparable to that of Association 1; however, the mean diversity of Association 3 (0.94) is higher than that of Association 1 (0.65). The *Elphidium clavatum*-*Elphidium incertum*-*asklundi*-*Haynesina orbicularis* association (No. 5), diversity 1.44 to 1.81, is present in the Russell map area. The average diversity of Association 5 (1.56) is the highest for the associations described here (Table 3).

Table 2. Radiocarbon dates for some samples used in this study

Sample Number	Laboratory Number	Species Dated	Age (years BP)	Elevation (m a.s.l.)	Locality	Reference
¹ 1	GSC-2863	<i>Macoma balthica</i> (Linné)	11 500 $\pm$ 200	145	Saint-Sixte, Papineau County, Quebec	Lowdon and Blake, 1980; Richard, 1980
2	GSC-2878	<i>Macoma balthica</i> (Linné)	11 500 $\pm$ 210	182	Mayo, Papineau County, Quebec	Lowdon and Blake, 1980; Richard, 1980
3	GSC-2763	<i>Hiattella arctica</i> (Linné)	11 400 $\pm$ 140	180	Buckingham, Papineau County, Quebec	Lowdon and Blake, 1980; Richard, 1980
6	GSC-2621	<i>Hiattella arctica</i> (Linné)	10 700 $\pm$ 100	146	Rivière-du-Lièvre, Papineau County, Quebec	Lowdon and Blake, 1978
7	GSC-2769	<i>Macoma balthica</i> (Linné)	11 800 $\pm$ 100	180	Val-des-Bois, Papineau County, Quebec	Lowdon and Blake, 1980; Richard, 1980
8A	GSC-3706	<i>Balanus hameri</i> (Ascanius)	11 000 $\pm$ 90	93	Navan, Ontario	Blake, 1984
8L	GSC-3743	<i>Macoma balthica</i> (Linné)	² 10 800 $\pm$ 90 ³ 10 700 $\pm$ 100	95	Navan, Ontario	This paper
10B	GSC-3907	<i>Hiattella arctica</i> (Linné)	² 10 200 $\pm$ 90 ³ 10 200 $\pm$ 110	69	Bearbrook, Ontario	This paper
24	GSC-2108	<i>Hiattella arctica</i> (Linné)	11 200 $\pm$ 100	106	Newington, Stormont County, Ontario	Richard, 1975b; Lowdon and Blake, 1979
36	GSC-3523	<i>Macoma balthica</i> (Linné)	11 800 $\pm$ 100	118-120	Merrickville, Grenville County, Ontario	Blake, 1984

¹Sample collected 1 m below dated level.

²Inner fraction.

³Outer fraction.

Cassidulina reniforme, *Elphidium clavatum*, and *Haynesina orbicularis* characterize Associations 4 and 7. *Haynesina orbicularis* and *E. clavatum* are the most abundant species in Associations 4 and 7, respectively. Association 4 occurs in the Winchester and Morrisburg map areas and Association 7 is present in the Winchester map area. The mean diversity of Association 4 is 1.39 and of Association 7

is 1.17. *Cassidulina reniforme*, *Islandiella helenae*, and *Haynesina orbicularis* are the dominant species of Association 6. The mean diversity of Association 6 (1.12) is lower than those of Associations 2, 4, 5, and 7 (Table 3). Association 6 is present in the Russell and Winchester map areas.

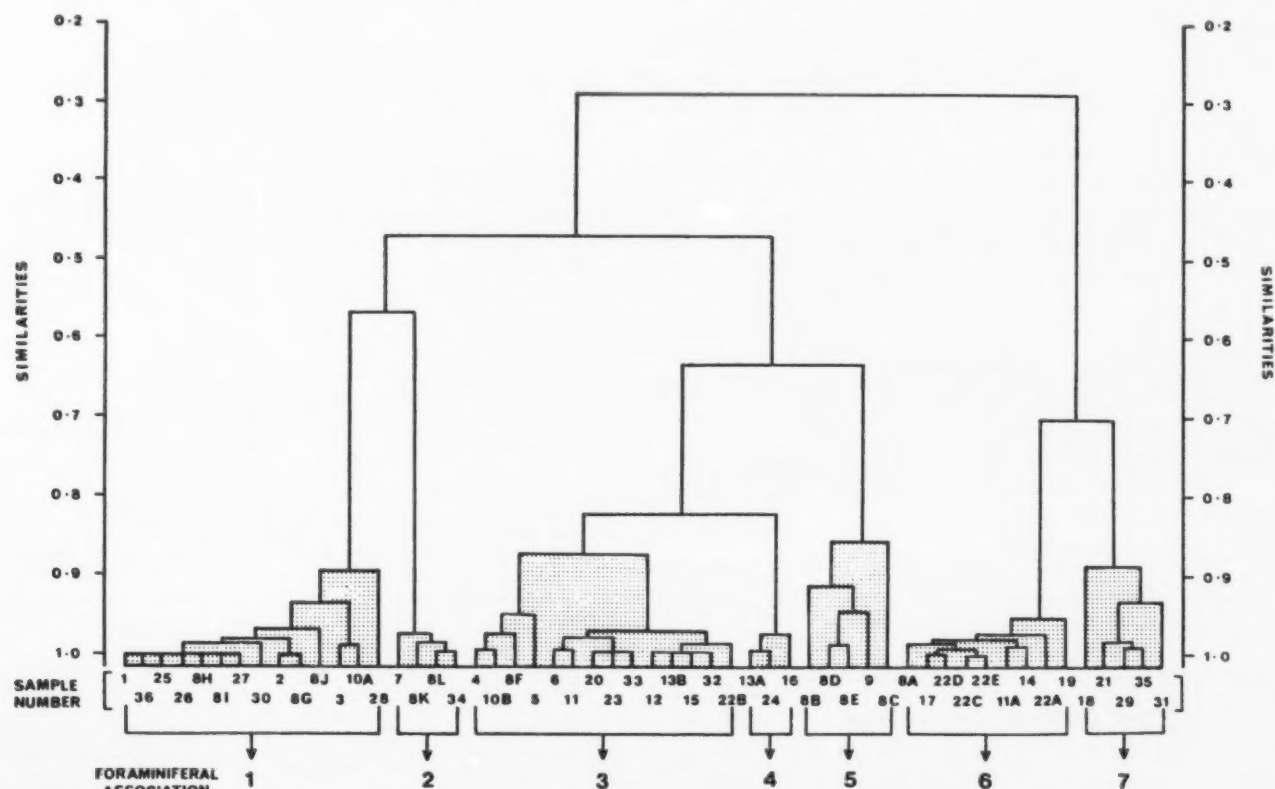


Figure 6. Dendrogram of weighted pair group cluster analysis of 54 samples.

Table 3. Mean per cent abundance of dominant benthonic foraminiferal taxa

Foraminiferal Association	1	2	3	4	5	6	7
<i>Cassidulina reniforme</i>				27.2		69.0	37.5
<i>Elphidium clavatum</i>	78.9	19.9	17.1	10.4	35.3		42.1
<i>Elphidium incertum/asklundi</i>					27.6		
<i>Elphidium</i> sp.		52.7					
<i>Haynesina orbicularis</i>	12.6	21.1	68.2	51.3	23.4	7.5	15.8
<i>Islandiella helenae</i>						9.8	
Number of samples	14	4	14	3	5	9	5
Number of taxa per sample	2-16	4-13	4-16	17-18	14-20	11-17	5-20
Foraminifer diversity [H(S)]	0.06-1.19	1.05-1.57	0.14-1.47	1.26-1.54	1.44-1.81	0.76-1.45	0.82-1.38
Mean foraminifer diversity [H(S)]	0.65	1.24	0.94	1.39	1.56	1.12	1.17

Table 4. Benthonic foraminiferal taxa from the Thurso, Russell, Winchester, and Morrisburg map areas; presence in Associations.

Taxon	Association						
	1	2	3	4	5	6	7
<i>Astrononion gallowayi</i> Loeblich and Tappan	x	x	x	x	x	x	x
<i>Buccella calida</i> (Cushman and Cole)	x		x				
<i>Buccella frigida</i> (Cushman)			x				
<i>Buliminella</i> sp.							
<i>Cassidulina reniforme</i> Nørvang	x	x	x	x	x	x	x
<i>Cibicides lobatulus</i> (Walker and Jacob)	x	x	x	x	x	x	x
<i>Cyclogyra involvens</i> (Reuss)					x		
<i>Dentalina baggi</i> Galloway and Wissler						x	x
<i>Dentalina frobisherensis</i> Loeblich and Tappan				x			x
" <i>Dentalina</i> " <i>ittai</i> Loeblich and Tappan				x		x	
<i>Elphidium clavatum</i> Cushman	x	x	x	x	x	x	x
<i>Elphidium incertum</i> /asklundi (Williamson)/Brotzen	x	x	x	x	x	x	x
<i>Elphidium subarcticum</i> Cushman	x	x	x	x	x	x	x
<i>Elphidium</i> sp.	x	x	x	x	x	x	
<i>Entolinguina translucida</i> (Heron-Allen and Earland)	x						
<i>Eoeponidella pulchella</i> (Parker)	x	x	x	x	x	x	x
<i>Fissurina cucurbitasema</i> Loeblich and Tappan						x	
<i>Fissurina laevigata</i> Reuss	x		x	x		x	x
<i>Fissurina marginata</i> (Montagu)				x	x	x	x
<i>Fissurina reniformis</i> (Sidebottom)	x	x	x		x	x	x
<i>Fissurina serrata</i> (Schlumberger)				x		x	
<i>Fissurina ventricosa</i> (Wiesner)	x		x			x	x
<i>Fissurina</i> sp.							x
<i>Fursenkoina loeblichii</i> (Feyling-Hanssen)	x		x	x	x	x	x
<i>Fursenkoina</i> sp.						x	x
<i>Glabratella</i> sp.	x			x	x		
<i>Glandulina laevigata</i> d'Orbigny					x	x	
<i>Glandulinid</i> 1					x		
<i>Glandulinid</i> 2					x		
<i>Haynesina orbicularis</i> (Brady)	x	x	x	x	x	x	x
<i>Islandiella helenae</i> Feyling-Hanssen and Buzas	x	x	x	x	x	x	x
<i>Islandiella norcrossi</i> (Cushman)	x	x	x	x	x	x	x
<i>Lagena semilineata</i> Wright						x	
<i>Lagena</i> sp.						x	
<i>Laryngosigma williamsoni</i> (Terquem)				x	x		
<i>Oolina acuticostata</i> (Reuss)						x	
<i>Oolina borealis</i> Loeblich and Tappan					x	x	
<i>Oolina hexagona</i> (Williamson)	x	x	x	x	x	x	
<i>Oolina lineata</i> (Williamson)				x	x	x	x
<i>Oolina melo</i> d'Orbigny	x			x	x	x	x
<i>Oolina squamosa-sulcata</i> (Heron-Allen and Earland)	x						
<i>Oolina williamsoni</i> (Alcock)			x	x		x	
<i>Oolina</i> sp.					x		
<i>Parafissurina fusuliformis</i> Loeblich and Tappan			x	x			
<i>Patellina corrugata</i> Williamson					x	x	x
<i>Pateoris hauerinoides</i> (Rhumbler)	x		x		x		
Polymorphinid	x	x	x	x	x	x	x
<i>Pseudoparrella takayanagii</i> (Iwasa)			x	x		x	x
<i>Quinqueloculina seminulum</i> (Linné)	x	x	x	x	x		
<i>Rotalid</i> 1	x		x	x	x		
<i>Rotalid</i> 2					x		
<i>Trifarina hughesi</i> (Galloway and Wissler)						x	
<i>Triloculina trihedra</i> Loeblich and Tappan					x	x	
Number of taxa	25	15	25	28	32	36	24
Number of samples	14	4	14	3	5	9	5

Two successions of foraminiferal associations are recognized. The *Cassidulina reniforme*-*Islandiella helenae*-*Haynesina orbicularis* association (6) is replaced by the *Haynesina orbicularis*-*Elphidium clavatum* association (3) at Site 11 in the Russell map area and Site 22 in the Winchester map area. At both sites the succession of foraminiferal associations is accompanied by a succession from the *Balanus hameri* to *Hiatella arctica* macrofaunal association. A succession from the *Balanus hameri* to *Hiatella arctica* to *Mytilus edulis* to *Macoma balthica* macrofaunal association accompanies a different foraminiferal succession at Site 8 in the Russell map area. The successions of foraminiferal and macrofaunal associations at Site 8 are shown in Table 5.

Cronin (1979a) recognized two foraminiferal biofacies from Q-mode factor analysis of 54 samples from southeastern Ontario, southern Quebec, Champlain Valley of

New York and Vermont, and the Quebec City region. The nearshore shallow water Biofacies 1 consists of six sample groupings (associations of this study) and the offshore deep water Biofacies 2 consists of two sample groupings. Sample grouping A of Biofacies 1 is comparable to Association 3, and the two sample groups B and D of Biofacies 2 are comparable to Associations 5 and 6, respectively.

OSTRACODE ASSEMBLAGES

A total of 4457 ostracode valves were counted from 52 samples. Twenty-five samples yielded more than 35 valves (Table 1). Thus, the ostracode data were not analyzed quantitatively. Samples are arranged into five groups based on visual inspection of abundance data (Table 6).

Table 5. Successions of macrofaunal and foraminiferal associations at Site 8 near Navan, Ontario

Foraminiferal Association					
Number	Dominant Taxa	¹ Foraminiferal Ecozone	Sample Number	Macrofaunal Association	Date (years BP)
2	Elphidium sp.	FD	8L	Macoma balthica	² 10 800 ± 90 ³ 10 700 ± 100 (GSC-3743)
	Haynesina orbicularis		8K		
1	Elphidium clavatum Haynesina orbicularis	FC	8J	Mytilus edulis	
			8I		
			8H 8G		
3	Haynesina orbicularis Elphidium clavatum	FB	8F	Hiatella arctica	
5	Elphidium clavatum Elphidium incertum/asklundi Haynesina orbicularis		8E		
			8D		
		8C 8B			
6	Cassidulina reniforme Islandiella helenae Haynesina orbicularis	FA	8A	Balanus hameri	11 000 ± 90 (GSC-3706)

¹See Figure 5, ²Inner Fraction, ³Outer Fraction

¹See Figure 5, ²Inner Fraction, ³Outer Fraction

Table 6. Ostracode taxa from the Thurso, Russell, Winchester, and Morrisburg map areas. Counts for samples containing more than 35 valves.

Ostracode Assemblage Group	A			B						C								D				E			Unassigned	
Sample Number	1	26	31	3	7	8K	8L	28	36	8D	8E	8F	8G	8H	8I	8J	10A	10B	20	22B	8B	8C	9	21	24	
<i>Acanthocythereis dunelmensis</i> (Norman)																									1	
<i>Argilloecia</i> sp.																									1	
<i>Baffinicythere emarginata</i> (Sars)																									13	
Cypridae Indet.	20	13						3	4	1	1	2									2			1	1	
<i>Cythere lutea</i> O.F. Müller											6		31		2	3						5				
<i>Cytheromorpha macchesneyi</i> (Brady and Crosskey)	13	12		46	113	17	70	90	54			1								1					1	
<i>Cytheropteron arcuatum</i> Brady, Crosskey and Robertson								3																	11	
<i>Cytheropteron champlainum</i> Cronin								1		6	1										31	7	7	2	3	
<i>Cytheropteron inflatum</i> Brady, Crosskey and Robertson		4									2	1		1							14	3	9	2		
<i>Cytheropteron latissimum</i> (Norman)				16		15	3	1	1	56	67	134	72	74	123	20		1		1	7	19	2		8	
<i>Cytheropteron nealei</i> Cronin																					7		3			
<i>Cytheropteron nodosum</i> Brady											9							3			83	46	22		8	
<i>Cytheropteron paralatissimum</i> Swain																					1				12	
<i>Cytheropteron pseudomontrosiense</i> Whatley and Masson	36	94	156	1		1		4																	2	
<i>Cytherura similis</i> Sars										1		2														
<i>Eucythere argus</i> (Sars)						3				2	2		5							2						
<i>Finnarchinella logani</i> (Brady and Crosskey)																					3	1	1			
<i>Heterocyprideis sorbyana</i> (Jones)					9	16	29			44	96	118	30	14	10		30	25	33	23	64	93	12		1	
<i>Palmenella limicola</i> (Norman)																									4	
<i>Roundstonia globulifera</i> (Brady)						1		1			1	1	1												2	
<i>Sarsicytheridea bradii</i> (Norman)					3	3				2	72	102	70	26	24	8	7	1	7	8						
<i>Sarsicytheridea macrolaminata</i> (Elofson)					7	1				12	43	47	7	13	6	5	6	4	1		42	27	16			
<i>Sarsicytheridea punctillata</i> (Brady)					3	18	3			51	218	280	95	33	59	3	69	53	39	10	154	121	16			
<i>Sclerochilus contortus</i> (Norman)										1											2	2				
¹ Ostracode diversity [H(S)]	0.75 0.59			0.00 1.23 1.03						1.56 1.62 1.52 1.66 1.42 1.20								1.08				1.77 1.63				
² Macrofaunal association	PA	PA	--	HA	MB	MB	MB	MB	MB	HA	HA	HA	HA	HA	HA	ME	HA	HA	HA	HA	HA	HA	HA	PA	HA	
³ Foraminiferal association	1	1	7	1	2	2	2	1	1	5	5	3	1	1	1	1	1	3	3	3	5	5	5	7	4	

Note: *Ilyocypris gibba* (Ramdohr) present in sample 4 that contained less than 35 valves.
¹Diversity computed for samples containing more than 100 valves.
²HA, *Hiatella arctica*; MB, *Macoma balthica*; ME, *Mytilus edulis*; PA, *Portlandia arctica*.
³See Table 3 for dominant taxa of foraminiferal associations.

Group A assemblages, consisting of three samples from the Thurso and Morrisburg map areas, are characterized by *Cytheropteron pseudomontrosiense* and appear to be restricted to clay. Diversities of 0.59 and 0.75 were obtained for two samples that contained more than 100 valves. The *Elphidium clavatum*-*Haynesina orbicularis* association (1), *Elphidium clavatum*-*Cassidulina reniforme*-*Haynesina orbicularis* association (7), and the *Portlandia arctica* association accompany Group A ostracode assemblages. *Cytheromorpha macchesneyi* is abundant in the samples comprising Group B. Diversity ranges from 0.00 to 1.23. Group B assemblages are from the Thurso, Russell, and Morrisburg map areas and the dated levels at the Val-des-Bois and Merrickville sites. The *Elphidium clavatum*-*Haynesina orbicularis* association (1), *Haynesina orbicularis*-*Elphidium clavatum* association (3), the *Hiatella arctica* and *Macoma balthica* associations accompany Group B assemblages. Group C assemblages, characterized by *Cytheropteron latissimum* and *Sarsicytheridea punctillata*, are present in the Russell map area. Diversity ranges from 1.20 to 1.66. The *Elphidium clavatum*-*Haynesina orbicularis* association (1), *Haynesina orbicularis*-*Elphidium clavatum* association (3), *Elphidium clavatum*-*Elphidium incertum/asklundi*-*Haynesina orbicularis* association (5), the *Hiatella arctica* and *Mytilus edulis* associations accompany Group C assemblages. *Sarsicytheridea punctillata* and *Heterocyprideis sorbyana* are abundant in the samples from the Russell and Winchester map areas comprising Group D. The *Elphidium clavatum*-*Haynesina orbicularis* association (1), *Haynesina orbicularis*-*Elphidium clavatum* association (3), and the *Hiatella arctica* association accompany Group D assemblages. The assemblages from the Russell map area comprising Group E are characterized by *Sarsicytheridea punctillata*, *Cytheropteron nodosum*, and *Heterocyprideis sorbyana*. Diversities of 1.63 and 1.77 were obtained for two Group E samples. The *Elphidium clavatum*-*Elphidium incertum/asklundi*-*Haynesina orbicularis* association (5) and the *Hiatella arctica* association accompany Group E assemblages. Two samples (21 and 24) from the Winchester map area are not assigned to any group (Table 6).

Radiocarbon dates for some of the *Cytheromorpha macchesneyi*-dominant assemblages (Group B) are shown in Table 7. Cronin (1977a, 1981) pointed out that *C. macchesneyi* is characteristic of the Transitional phase

circa 12 500 to 11 600 BP in Champlain Valley. He noted that the abundance of *C. macchesneyi* is lower during the *Hiatella arctica* phase (11 600 to between 11 000 and 10 600 BP) and the *Mya arenaria* phase (between 11 000 and 10 600 to 10 000 BP) by comparison with its abundance in the Transitional phase. The radiocarbon dates indicate that *Cytheromorpha macchesneyi*-dominant assemblages are recurrent and are not restricted to the early part of the marine episode in the western Champlain Sea basin.

The assemblages comprising Groups C, D, and E are comparable to those described by Cronin (1981) for the *Hiatella arctica* phase. *Cytheropteron pseudomontrosiense*-dominant assemblages (Group A) were not reported previously from the Champlain Sea basin. Gunther and Hunt (1976, 1977) pointed out that *C. pseudomontrosiense* (*C. montrosiense* of Gunther and Hunt) is present in the lower part and absent in the upper part of the marine clay unit penetrated by piston cores in Lake Champlain. Only six valves of the species were observed by Cronin (1981) in 2 of 38 samples that he examined from surface exposures in Ontario, Quebec, and Champlain Valley.

DEPOSITIONAL ENVIRONMENT

Successions of macrofaunal and foraminiferal associations described above are related to changing bottom water properties, variations in substrate, and decreasing water depth. They are used to interpret the depositional environment of the late glacial and postglacial marine sediments in the study area. Foraminiferal Association 6 and the *Balanus hameri* or *Portlandia arctica* association occur at the base of the successions. *Cassidulina reniforme*, *Islandiella helenae* Feyling-Hanssen and Buzas, and *Haynesina orbicularis* are the dominant species of Association 6 (Table 3). Hillaire-Marcel (1980) concluded that the *Portlandia arctica* community (association of this study) is accompanied by *Islandiella helenae* (*I. teretis* of Hillaire-Marcel) in clay that was deposited in the deeper parts of the Champlain Sea basin where the temperature was about 0°C and salinity was greater than 30‰. He also pointed out that the cirriped *Balanus hameri* is most abundant in the deeper parts of the basin. Corliss et al. (1982) reported that the *Cassidulina reniforme*-*Islandiella helenae*-dominant assemblages they observed at the base of the Late

Table 7. Radiocarbon dates for *Cytheromorpha macchesneyi*-dominant assemblages from the western Champlain Sea basin

Sample Number	Age (years BP)	Laboratory Number	Association	
			Pelecypod	Foraminifer (number)
8L	¹ 10 800 ± 90 ² 10 700 ± 100	GSC-3743	<i>Macoma balthica</i>	<i>Elphidium</i> sp. <i>Haynesina orbicularis</i> <i>Elphidium clavatum</i> (Association 2)
7	11 800 ± 100	GSC-2769		
3	11 400 ± 140	GSC-2763	<i>Hiatella arctica</i>	<i>Elphidium clavatum</i>
36	11 800 ± 100	GSC-3523	<i>Macoma balthica</i>	<i>Haynesina orbicularis</i> (Association 1)
¹ Inner fraction ² Outer fraction				

Pleistocene marine unit in cored sections from Lake Champlain are characteristic of nearly normal marine conditions in the Champlain Sea. Therefore, Association 6, *Cassidulina reniforme*-*Islandiella helenae*-*Haynesina orbicularis*-dominant, and the *Balanus hameri* or *Portlandia arctica* association colonized the highest salinity bottom water that was present in the Champlain Sea basin. Association 6 accompanies the *Balanus hameri* association in pebbly clayey sand and pebbly sand/clay, the *Macoma balthica* association in sandy clay, and the *Portlandia arctica* association in clay. Foraminiferal assemblages, *Cassidulina reniforme*-*Islandiella helenae*-dominant, comparable to those of Association 6, are present near the base of the marine clay unit described by Gadd (1977) from cored sections in Ottawa Valley (C.G. Rodrigues, unpublished data).

In core M74-10 of Corliss et al. (1982), *Cassidulina reniforme*-*Islandiella helenae*-dominant assemblages are replaced by assemblages in which *I. helenae* is rare to absent and *Haynesina orbicularis*, *C. reniforme*, and *Elphidium clavatum* are abundant. The low frequency of *I. helenae* and the higher frequency of *E. clavatum* in the latter assemblages are related to lower salinity compared to that for the *Cassidulina reniforme*-*Islandiella helenae*-dominant assemblages. The assemblages characterized by *Haynesina orbicularis*, *Cassidulina reniforme*, and *Elphidium clavatum* in core M74-10 are comparable to the assemblages comprising Associations 4 and 7 (Table 3). A succession from Association 6 to either Association 4 or 7 was not observed in the study area. The successions should be present near the base of the marine clay unit described by Gadd (1977) from cored sections in Ottawa Valley.

Associations 4, 6, and 7 colonized the high salinity layer that was present in the deeper parts of the western Champlain Sea basin. Association 6 characterizes the lower part of the high salinity layer where salinity was highest, and Associations 4 and 7 colonized the upper part of the high salinity layer in which the salinity was slightly lower. The *Hiatella arctica* and *Macoma balthica* associations accompany Association 4 and the *Portlandia arctica* association accompanies Association 7.

Association 5 and the *Hiatella arctica* association replace Association 6 and the *Balanus hameri* association at Site 8 in the Russell map area (Table 5). At the Rivière-Beaudette site of Rodrigues and Richard (1983), Association 5 replaces an assemblage in which *Astrononion gallowayi* Loeblich and Tappan and *Cassidulina reniforme* are abundant. The low frequency of *C. reniforme* in Association 5 (Table 3) indicates lower salinity by comparison with Associations 4, 6, and 7. The *Elphidium clavatum*-*Elphidium incertum*-*asklundi*-*Haynesina orbicularis* association (5) appears to be restricted to coarse grained pebbly and sandy substrates. The absence of assemblages comparable to those of Association 5 in the cores that penetrated marine clay in Lake Champlain (A.S. Hunt, personal communication, 1984) is consistent with the substrate relationship recognized for the foraminiferal association in the western Champlain Sea basin.

At Site 8, Association 5 is replaced by the *Haynesina orbicularis*-*Elphidium clavatum* association (3), and Association 3 is replaced by Association 1, *Elphidium clavatum*-*Haynesina orbicularis*-dominant (Table 5). Associations 1 and 3 are related to lower salinity bottom water compared to Association 5 and shallow water depths at least during the latter part of the marine episode in the western Champlain Sea basin. The presence of *Elphidium clavatum*-dominant assemblages in the uppermost part of the marine sequence in cores M74-10 and M75-4 of Corliss et al. (1982) and the succession from Association 3 to Association 1 at Site 8 suggest that Association 3 (*Haynesina orbicularis* > *Elphidium clavatum*, Table 3) inhabited bottom

water with higher salinity compared to that colonized by Association 1 (*Elphidium clavatum* > *Haynesina orbicularis*). The *Haynesina orbicularis*-*Elphidium clavatum* association (3) is accompanied by the *Hiatella arctica* and *Macoma balthica* associations, and the *Elphidium clavatum*-*Haynesina orbicularis* association (1) is accompanied by the *Hiatella arctica*, *Macoma balthica*, *Mytilus edulis*, and *Portlandia arctica* associations. Foraminiferal assemblages characterized by *Elphidium clavatum*, that is, comparable to those of Association 1, are present in the upper part of the marine clay unit and in the lower part of the red- and grey-banded silt and clay unit described by Gadd (1977) from cored sections in Ottawa valley (C.G. Rodrigues, unpublished data).

The *Elphidium* sp.-*Haynesina orbicularis*-*Elphidium clavatum* association (2) replaces Association 1 at the top of the section at Site 8 (Table 5). Rodrigues and Richard (1983) described an assemblage characterized by *Elphidium* sp. (*E. albiumbilicatum* of Rodrigues and Richard) from the top of the foraminiferal succession at their Rivière-Beaudette site. The *Macoma balthica* association accompanies Association 2 at Site 8 whereas the *Mya arenaria* association and an *Elphidium* sp.-dominant assemblage occur together at the Rivière-Beaudette site. An *Elphidium* sp.-dominant assemblage and the *Macoma balthica* association occur at the top of a marine clay unit that is overlain by sand containing the freshwater pelecypod *Lampsilis* at the Saint-Stanislas-de-Kostka site of Rodrigues and Richard (1983). Therefore, Association 2 colonized the lowest salinity bottom water in the western Champlain Sea basin and is related to a water depth as shallow as or shallower than that for Association 1. The relationship between the faunal associations and paleosalinity is summarized in Table 8.

The *Hiatella arctica* association accompanies Association 4 in the upper part of the high salinity layer and Associations 1, 3, and 5 which are characteristic of lower salinity. The *Macoma balthica* association accompanies Associations 4 and 6 in the high salinity layer whereas the pelecypod association and Associations 1, 2, and 3 colonized lower salinity bottom water. Conversely, the *Balanus hameri* association and Association 6 are restricted to the high salinity layer. The same trend between the *Balanus hameri* association and *Cassidulina reniforme*-dominant assemblages comparable to those comprising Association 6 was observed in samples from the Kemptville (31 G/4), Vaudreuil (31 G/8), and Huntingdon (31 G/1) map areas. Thus, the *Hiatella arctica* and *Macoma balthica* associations are euryhaline compared to the *Balanus hameri* association that appears to be stenohaline. The *Elphidium clavatum*-*Elphidium incertum*-*asklundi*-*Haynesina orbicularis* association (5) and the *Balanus hameri* association are restricted to pebbly clayey sand and pebbly sandy clay whereas the *Portlandia arctica* association is restricted to clay. The *Portlandia arctica* association accompanies Associations 6 and 7 in the high salinity layer and Association 1 in lower salinity bottom water. The relationship between the *Portlandia arctica* association and the foraminiferal associations indicates that the pelecypod association is euryhaline.

Elson (1969a) reported that the earlier deep water phase of the Champlain Sea, i.e., the *Hiatella* phase, was characterized by a subarctic fauna typified by *Hiatella arctica*. In the western Champlain Sea basin, the *Hiatella arctica* association, i.e., assemblages in which *H. arctica* is the most abundant species, accompanies Association 4 in the upper part of the high salinity layer and Associations 5, 3, and 1 in lower salinity bottom water (Table 8). The highest salinity bottom water that was present in the western Champlain Sea basin was characterized by Association 6 and the *Portlandia arctica* association in clay or the *Macoma balthica* association in sandy clay or the *Balanus hameri* association in coarse grained pebbly and sandy substrates.

Table 8. Inferred paleosalinity for Late Pleistocene ostracode assemblages and cirriped, pelecypod, and foraminiferal associations from the western Champlain Sea basin

Foraminiferal Association			Macrofaunal Association	Ostracode Assemblage		Lithology	Salinity of Bottom Water	¹ Radiocarbon Dates (years BP)
Number	Dominant Taxa	Diversity [H(S)]		Abundant Species	Group			
2	<i>Elphidium</i> sp. <i>Haynesina orbicularis</i> <i>Elphidium clavatum</i>	Range: 1.05-1.57 Mean: 1.24	<i>Macoma balthica</i>	<i>Cytheromorpha macchiesneyi</i>	B	Clayey sand Sand	Low (10-20‰)	10 800 ± 90 (IF) ² (GSC-3743) 10 700 ± 100 (OF) ³ 11 800 ± 100 (GSC-2769)
1	<i>Elphidium clavatum</i> <i>Haynesina orbicularis</i>	Range: 0.06-1.19 Mean: 0.65	<i>Hiatella arctica</i>	<i>Cytheromorpha macchiesneyi</i>	B	Pebbly sandy clay	Intermediate (20-30‰)	11 400 ± 140 (GSC-2763) *11 500 ± 210 (GSC-2878)
			<i>Macoma balthica</i>			Sandy clay Clayey sand		11 800 ± 100 (GSC-3523)
			<i>Hiatella arctica</i>	<i>Cytheropteron latissimum</i>	C	Clay Sandy clay		
			<i>Mytilus edulis</i>	<i>Sarsicytheridea punctillata</i>		Clay		
			<i>Portlandia arctica</i>	<i>Cytheropteron pseudomontrosiense</i>	A	Clay		⁵ 11 500 ± 200 (GSC-2863)
3	<i>Haynesina orbicularis</i> <i>Elphidium clavatum</i>	Range: 0.14-1.47 Mean: 0.94	<i>Hiatella arctica</i>	<i>Sarsicytheridea punctillata</i>	D	Sand Pebbly sand	Intermediate (20-30‰)	10 200 ± 90 (IF) ² (GSC-3907) 10 200 ± 110 (OF) ³ ⁶ 10 700 ± 100 (GSC-2621)
				<i>Heterocyprideis sorbyana</i>				
				<i>Cytheropteron latissimum</i> <i>Sarsicytheridea punctillata</i>	C	Sandy clay		
			<i>Macoma balthica</i>	(Ostracodes are rare)		Sandy clay Clayey sand Pebbly sand		
5	<i>Elphidium clavatum</i> <i>Elphidium incertum/asklandi</i> <i>Haynesina orbicularis</i>	Range: 1.44-1.81 Mean: 1.56	<i>Hiatella arctica</i>	<i>Cytheropteron latissimum</i> <i>Sarsicytheridea punctillata</i>	C	Pebbly clayey sand Pebbly sandy clay	High (30-34‰)	11 200 ± 100 (GSC-2108)
				<i>Sarsicytheridea punctillata</i>				
				<i>Cytheropteron nodosum</i> <i>Heterocyprideis sorbyana</i>	E			
7	<i>Elphidium clavatum</i> <i>Cassidulina reniforme</i> <i>Haynesina orbicularis</i>	Range: 0.82-1.38 Mean: 1.17	<i>Portlandia arctica</i>	<i>Cytheropteron pseudomontrosiense</i>	A	Clay	High (30-34‰)	11 000 ± 90 (GSC-3706)
4	<i>Haynesina orbicularis</i> <i>Cassidulina reniforme</i> <i>Elphidium clavatum</i>	Range: 1.26-1.54 Mean: 1.39	<i>Hiatella arctica</i>	(Ostracodes are rare)		Diamicton Pebbly sand		
			<i>Macoma balthica</i>			Clay		
6	<i>Cassidulina reniforme</i> <i>Islandiella helenae</i> <i>Haynesina orbicularis</i>	Range: 0.76-1.45 Mean: 1.12	<i>Balanus hameri</i>	(Ostracodes are rare)		Pebbly clayey sand Pebbly sandy clay	High (30-34‰)	11 000 ± 90 (GSC-3706)
			<i>Macoma balthica</i>			Sandy clay		
			<i>Portlandia arctica</i>			Clay		

¹ Radiocarbon dates are for samples containing the macrofaunal association, foraminiferal association, and ostracode group indicated except for notes (4) and (6) below.

² Inner fraction.

³ Outer fraction.

⁴ *Hiatella arctica* and *Macoma balthica* are equally abundant and ostracodes are rare at the dated level.

⁵ Minimum age; sample collected 1 m below dated level.

⁶ Ostracodes are rare at dated level.

The relationship between salinity and the faunal associations presented above indicates that *Hiatella arctica*-dominant assemblages were not characteristic of the highest salinity water that was present in the study area.

Elson (1969b) reported that the *Hiatella* phase lasted from about 11 800 to between 10 800 to 10 600 BP. The date of $10\ 200 \pm 90$ BP (GSC-3906, inner fraction) for the *Hiatella arctica* association at the top of the marine sequence at Site 10 (Fig. 2) indicates that *Hiatella arctica*-dominant assemblages are not restricted to the early part of the marine episode. Hillaire-Marcel (1980) and Rodrigues and Richard (1983) reached a similar conclusion.

FORAMINIFER DIVERSITY

Cronin (1979b) reported that foraminifer diversity [$H(S)$] in samples from Ontario ranges from 1.07 to 2.48 with a mean value of 1.69. He pointed out that diversity is consistently higher in the central part of the Champlain Sea basin in Ontario and Quebec compared to Champlain Valley where foraminifer diversity ranges from 0.50 to 1.79 with a mean value of 1.06. The mean foraminifer diversity for the samples from the central part of the western Champlain Sea basin, i.e., the samples from the Russell and Winchester map areas (Fig. 2), is 1.12 with a range of 0.14 to 1.81 (Table 1). The differences between the mean and range of foraminifer diversity reported here and those reported by Cronin (1979b) for the central part of the basin in Ontario are due, in part, to sample density. The diversities for the Russell and Winchester map areas are based on 35 samples by comparison with 7 samples used by Cronin.

Cronin (1979b) concluded that microfaunal diversity may be influenced by salinity. He suggested that values of $H(S)$ approaching 1.8 for foraminiferal assemblages from the Champlain Valley are related to normal marine conditions. Foraminifer diversity for the assemblages comprising Association 6 from the lower part of the high salinity layer ranges from 0.76 to 1.45 with a mean value of 1.12 (Table 8). The mean diversities for Associations 4 and 7 from the upper part of the high salinity layer, 1.39 and 1.17 respectively, are slightly higher than that of Association 6. The mean diversity of 1.24 for Association 2 which characterizes the lowest salinity bottom water in the western Champlain Sea basin is higher than those for Associations 6 and 7 from the high salinity layer. The highest diversity for the samples used in this study is 1.81 for a sample comprising Association 5 that is related to lower salinity compared to the high salinity layer. The mean diversity of 1.56 for Association 5 is the highest for the foraminiferal associations described in this report.

The foraminiferal succession at Site 8 (Fig. 2) provides a direct test for the proposed relationship between foraminifer diversity and salinity. A succession from the high salinity Association 6 to the low salinity Association 2 was recognized at Site 8 (Table 5). Foraminifer diversity ranges from 1.44 to 1.81 for the samples comprising Associations 6, 5, and 3 from the lowest part of the succession, decreasing to as low as 0.71 for the samples of Association 1 in the upper part of the succession (Fig. 7). At the top of the succession diversity increases to as high as 1.57 in the samples of Association 2. Thus, there does not appear to be a direct relationship between salinity and foraminifer diversity [$H(S)$] in the western Champlain Sea basin.

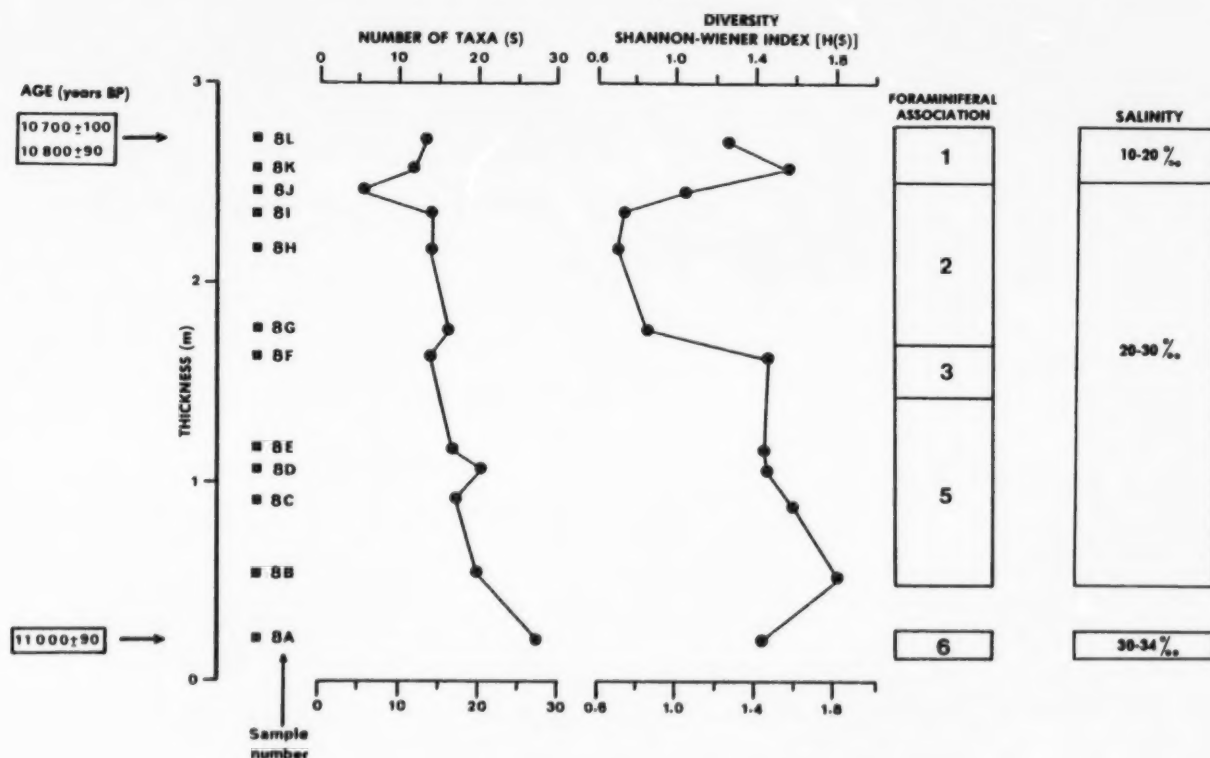


Figure 7. Temporal variation of foraminifer diversity [$H(S)$] at Site 8.

CONCLUSIONS

The marine *Balanus hameri*, *Hiatella arctica*, *Macoma balthica*, *Mytilus edulis*, and *Portlandia arctica* associations and the freshwater *Lampsilis* association are present in the study area. Seven foraminiferal associations are recognized from weighted pair group cluster analysis of 54 samples. *Cassidulina reniforme*, *Elphidium clavatum*, *Elphidium incertum/asklundi*, *Elphidium* sp., *Haynesina orbicularis*, and *Islandiella helenae* are abundant in the associations. Ostracodes are not as abundant as foraminifers in the study area. *Cytheromorpha macchesneyi*, *Cytheropteron latissimum*, *C. nodosum*, *C. pseudomontrosiense*, *Heterocyprideis sorbyana*, and *Sarsicytheridea punctillata* are abundant in the ostracode assemblages. *Cytheromorpha macchesneyi*-dominant assemblages are not restricted to the early part of the marine episode in the western Champlain Sea basin. The assemblages were present in the western part of the basin circa 11 800, 11 400, and 10 800 years ago and colonized cold, low salinity bottom water.

Salinity and substrate are two of the major factors influencing the geographic and temporal distribution of macrofossils and microfossils. The *Cassidulina reniforme*-*Islandiella helenae*-*Haynesina orbicularis* association and the *Balanus hameri* or *Macoma balthica* or *Portlandia arctica* association characterized the highest salinity bottom water that was present in the study area. The *Elphidium* sp.-*Haynesina orbicularis*-*Elphidium clavatum* and *Macoma balthica* associations and *Cytheromorpha macchesneyi*-dominant assemblages colonized the lowest salinity bottom water. The *Hiatella arctica*, *Macoma balthica*, and *Portlandia arctica* associations are euryhaline by comparison with the stenohaline *Balanus hameri* association. The *Balanus hameri* and *Elphidium clavatum*-*Elphidium incertum/asklundi*-*Haynesina orbicularis* associations occur in pebbly clayey sand and pebbly sandy clay whereas the *Portlandia arctica* association and *Cytheropteron pseudomontrosiense*-dominant assemblages are restricted to clay. Foraminifer diversity [H(S)] for 54 samples ranged from 0.06 to 1.81 with a mean value of 1.02. Ostracode diversity [H(S)] ranged from 0.00 to 1.77 for 14 samples that contained more than 100 valves. Foraminifer diversity does not appear to be directly related to salinity.

Successions of macrofaunal and foraminiferal associations are recognized in the study area. The *Balanus hameri* and the *Cassidulina reniforme*-*Islandiella helenae*-*Haynesina orbicularis* associations at the base of marine strata are replaced by the *Hiatella arctica* and the *Haynesina orbicularis*-*Elphidium clavatum* associations or the *Macoma balthica* and the *Elphidium* sp.-*Haynesina orbicularis*-*Elphidium clavatum* associations at the top of the marine strata. The successions are related, in part, to a change from high salinity bottom water (30 to 34‰) at the base to lower salinity bottom water (10 to 30‰) at the top of the successions. The change from high to low salinity bottom water in the Navan area occurred between 11 000 and 10 800 BP on the basis of radiocarbon ages of 11 000 ± 90 BP (GSC-3706) for plates of *Balanus hameri* and 10 800 ± 90 BP (GSC-3743, inner fraction) for shells of *Macoma balthica* from the base and top of a marine sequence.

Dates of 10 200 ± 90 and 10 200 ± 110 BP (GSC-3907) inner and outer fractions, respectively, were obtained for shells of *Hiatella arctica* from a shell bed at the top of a fossiliferous sequence near Bearbrook. The dates indicate that the *Hiatella arctica* association is not restricted to the early part of the marine episode in the study area. The dates on *Hiatella arctica* overlap with the Russell date of 10 000 ± 320 BP (GSC-1553) for shells of *Macoma* spp. from a comparable elevation and are almost identical to the date of 10 200 ± 90 BP (GSC-1968) for freshwater *Lampsilis* shells that were collected about 16 m below the dated *Hiatella arctica* shells. The date of 11 800 ± 100 BP (GSC-3523) for

shells of *Macoma balthica* from a beach deposit near marine limit at an elevation of about 119 m and 4.5 km southeast of Merrickville gives a minimum age for the deglaciation and marine submergence along the southwestern rim of the Champlain Sea basin in the Smiths Falls-Brockville area.

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Cytheropteron inflatum Brady, Crosskey and Robertson: Whatley and Masson, 1979, Rev. Español Micropal., v. 11, no. 2, p. 237, Pl. 8, fig. 8, 13-16.

Cytheropteron latissimum (Norman): Whatley and Masson, 1979, Rev. Español Micropal., v. 11, no. 2, p. 225, Pl. 6, fig. 7, 9, 12.

Cytheropteron nealei Cronin, 1981, Micropaleontology, v. 27, no. 4, p. 406, Pl. 7, fig. 7.

Cytheropteron nodosum Brady: Whatley and Masson, 1979, Rev. Español Micropal., v. 11, no. 2, p. 242, fig. 1-3.

Cytheropteron paralatissimum Swain, 1963, Jour. Paleont., v. 37, no. 4, p. 817, Pl. 95, fig. 12; text-fig. 8b.

Cytheropteron pseudomontrosiense Whatley and Masson, 1979, Rev. Español Micropal., v. 11, no. 2, p. 247, Pl. 2, fig. 5, 7-10, 13-14.

Cytherura similis Sars = *Semicytherura similis* (Sars): Rosenfeld, 1977, Meyniana, v. 29, p. 33, Pl. 9, fig. 107-110; text-fig. 22-23.

Eucythere argus (Sars): Rosenfeld, 1977, Meyniana, v. 29, p. 20, Pl. 3, fig. 43-45; text-fig. 12.

Finnarchinella logani (Brady and Crosskey) = *Finnarchinella curvicostata* Neale, 1974, Bull. Brit. Mus. Nat. Hist. (Zool.), v. 27, no. 2, p. 90, Pl. 1, fig. 1-3; Pl. 2, fig. 3, 7-9, 13.

Heterocyprideis sorbyana (Jones): Rosenfeld, 1977, Meyniana, v. 29, p. 21, Pl. 3, fig. 34-41.

Ilyocypris gibba (Ramdohr): Delorme, 1970, Canadian Jour. Zool., v. 48, no. 6, p. 1253, fig. 15-24.

Palmenella limicola (Norman): Neale and Howe, 1975, Crustaceana, v. 25, no. 3, p. 426, Pl. 5, fig. 7-8.

Roundstonia globulifera (Brady): Neale, 1973, Rev. Micropal., v. 16, no. 2, p. 125, Pl. 1, fig. 1-16.

Sarsicytheridea bradleyi (Norman): Athersuch, 1982, in Fossils and Recent Ostracods, ed. R.H. Bate, E. Robinson, and L.M. Sheppard; Ellis Horwood Ltd., Chichester, p. 241, Pl. 7, fig. 2, 4; Pl. 8, fig. 1-4, 7a, 8c-e.

Sarsicytheridea macrolaminata (Elofson) = *Eucytheridea macrolaminata* (Elofson): van den Bold, 1961, Ann. Mag. Nat. Hist., ser. 13, v. 4, p. 296, text-fig. 21-25.

Sarsicytheridea punctillata (Brady): Athersuch, 1982, in Fossil and Recent Ostracods, ed. R.H. Bate, E. Robinson, and L.M. Sheppard; Ellis Horwood Ltd., Chichester, p. 241, Pl. 6, fig. 7-11; Pl. 7, fig. 1, 3, 5, 8f.

Sclerochilus contortus (Norman): Rosenfeld, 1977, Meyniana, v. 29, p. 38, Pl. 10, fig. 124.



PLATE 1

PLATE I
(Scanning Electron Micrographs)

- 1, 2 *Astrononion gallowayi* Loeblich and Tappan, GSC 79963, Sample 8A, x 100
- 3 *Fissurina laevigata* Reuss, GSC 79964, Sample 30, x 165
- 4 *Eoeponidella pulchella* (Parker), GSC 79965, Sample 8B, x 465
- 5 *Oolina lineata* (Williamson), GSC 79966, Sample 8A, x 105
- 6 *Oolina melo* d'Orbigny, GSC 79967, Sample 8B, x 95
- 7 *Oolina acuticostata* (Reuss), GSC 79968, Sample 8A, x 90
- 8 *Oolina williamsoni* (Alcock), GSC 79969, Sample 8A, x 115
- 9 *Fissurina reniformis* (Sidebottom), GSC 79970, Sample 9, x 410
- 10 *Trifarina hughesi* (Galloway and Wissler), GSC 79971, Sample 14, x 100
- 11 *Oolina squamosa-sulcata* (Heron-Allen and Earland), GSC 79972, Sample 10A, x 110
- 12 *Oolina hexagona* (Williamson), GSC 79973, Sample 8D, x 90
- 13 *Fissurina marginata* (Montagu), GSC 79974, Sample 8A, x 165
- 14 *Pateoris hauerinoides* (Rhumbler), GSC 79975, Sample 8D, x 115
- 15 *Buccella calida* (Cushman and Cole), GSC 79976, Sample 8H, x 180

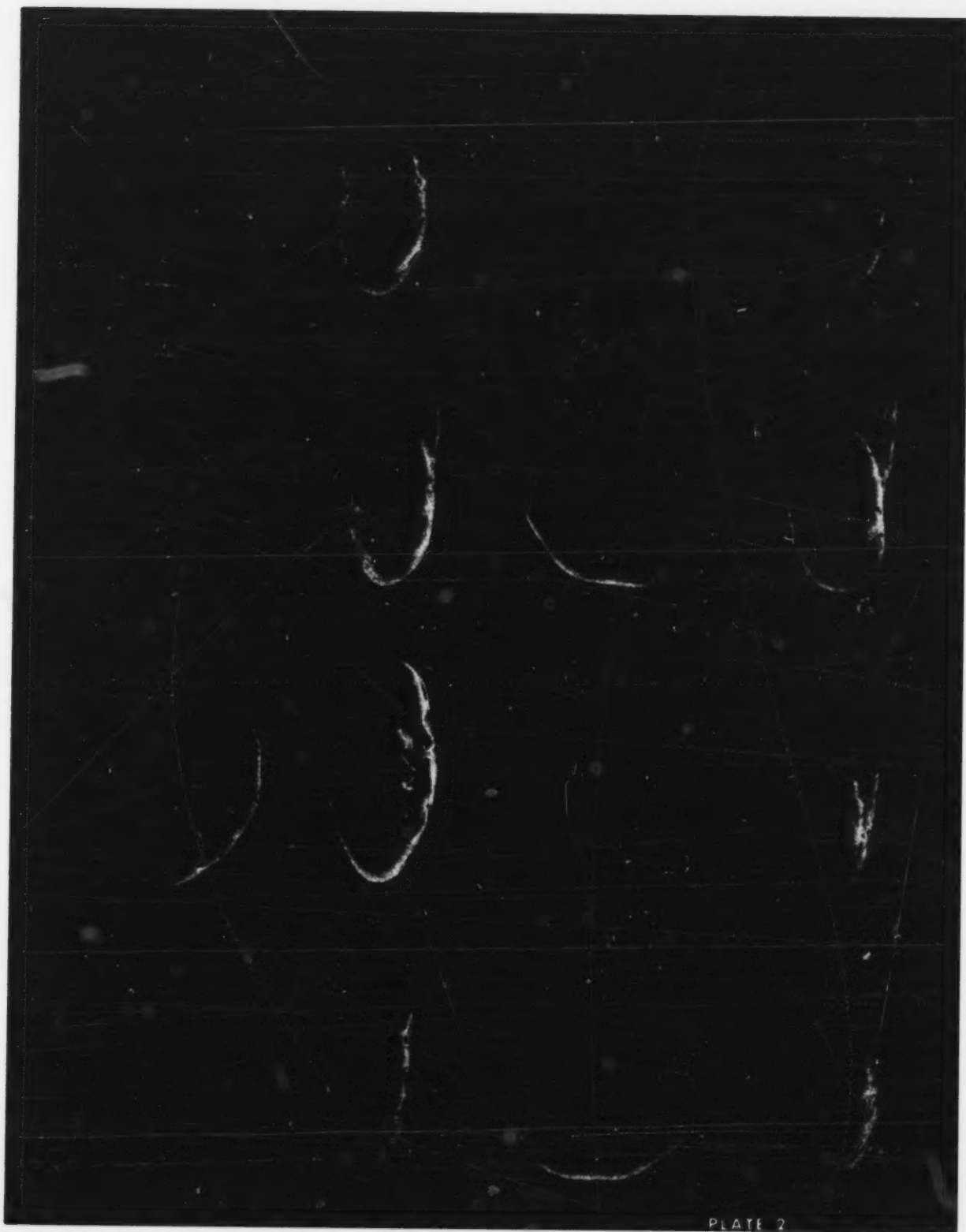


PLATE 2

PLATE 2
(Scanning Electron Micrographs)

- 1, 2 *Elphidium clavatum* Cushman, GSC 79977, Sample 31, x 100
- 5, 6 *Elphidium clavatum* Cushman, GSC 79978, Sample 31, x 100
- 9, 10 *Elphidium clavatum* Cushman, GSC 79979, Sample 31, x 105
- 3, 4 *Elphidium subarcticum* Cushman, GSC 79980, Sample 8H, x 90
- 7, 8 *Elphidium incertum/asklundi* (Williamson)/Brotzen, GSC 79981, Sample 8E, x 55
- 11, 12 *Elphidium incertum/asklundi* (Williamson)/Brotzen, GSC 79982, Sample 8E, x 65
- 13, 14 *Elphidium* sp., GSC 79983, Sample 8L, x 70
- 15, 16 *Haynesina orbicularis* (Brady), GSC 79984, Sample 8E, x 80

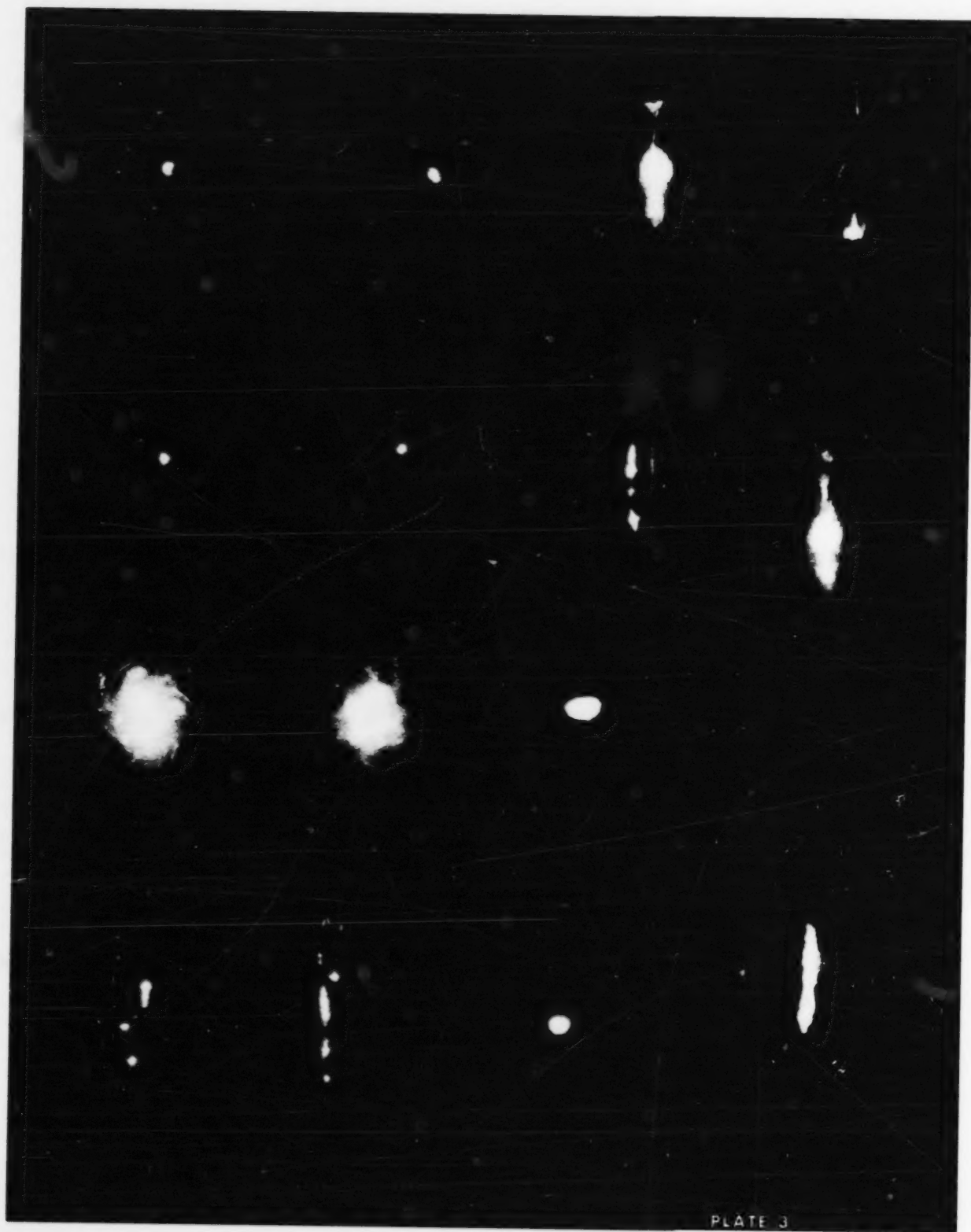


PLATE 3

PLATE 3
(Photomicrographs)

- 1, 2 *Islandiella norcrossi* (Cushman), GSC 79985, Sample 8A, x 80
- 3 *Entolingulina translucida* (Heron-Allen and Earland), GSC 79986, Sample 8G, x 150
- 4 *Lagena semilineata* Wright, GSC 79987, Sample 14, x 80
- 5, 6 *Islandiella helenae* Feyling-Hanssen and Buzas, GSC 79988, Sample 22A, x 60
- 7 "*Dentalina*" *ittai* Loeblich and Tappan, GSC 79989, Sample 17, x 75
- 8 *Fissurina curcurbitasema* Loeblich and Tappan, GSC 79990, Sample 8A, x 165
- 9, 10 *Cassidulina reniforme* Nørvang, GSC 79991, Sample 22A, x 50
- 11 *Fissurina reniformis* (Sidebottom), GSC 79970, Sample 9, x 190
- 12 *Fursenkoina loeblichii* (Feyling-Hanssen), GSC 79992, Sample 8A, x 80
- 13 *Fursenkoina loeblichii* (Feyling-Hanssen), GSC 79993, Sample 8A, x 80
- 14 *Fissurina ventricosa* (Wiesner), GSC 79994, Sample 14, x 160
- 15 *Fissurina serrata* (Schlumberger), GSC 79995, Sample 8A, x 150

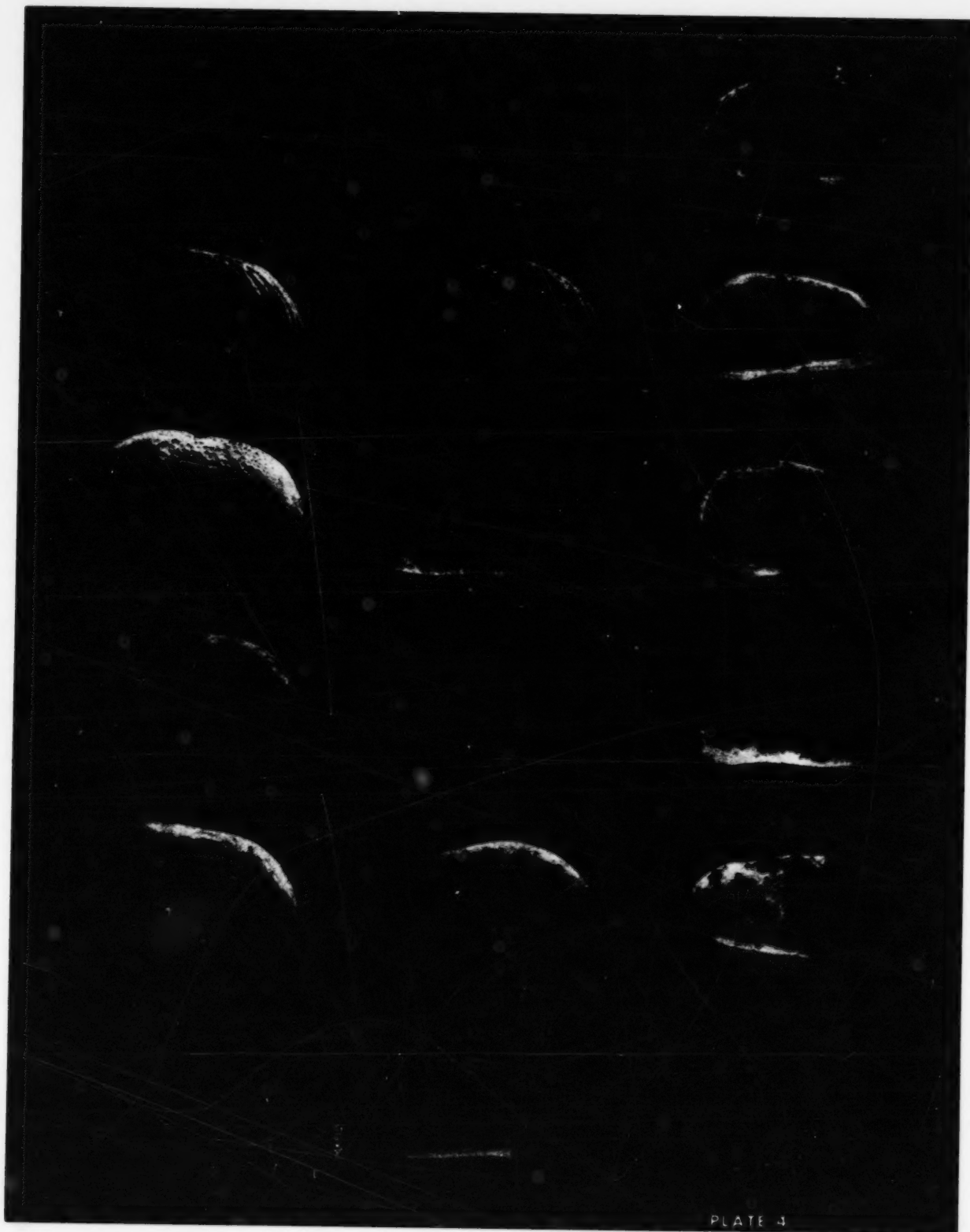


PLATE 4
(Scanning Electron Micrographs)

- 1, 3 *Baffinicythere emarginata* (Sars), GSC 79996, Sample 24, x 50 LV
- 2 *Baffinicythere emarginata* (Sars), GSC 79997, Sample 24, x 55 RV
- 4 *Heterocyprideis sorbyana* (Jones), GSC 79998, Sample 8B, x 40 LV
- 5, 6 *Heterocyprideis sorbyana* (Jones), GSC 79999, Sample 8B, x 40 RV
- 7 *Sarsicytheridea punctillata* (Brady), GSC 80000, Sample 8B, x 55 LV
- 8, 9 *Sarsicytheridea punctillata* (Brady), GSC 80001, Sample 8B, x 55 RV
- 10 *Sarsicytheridea bradii* (Norman), GSC 80002, Sample 8G, x 50 LV
- 11, 12 *Sarsicytheridea bradii* (Norman), GSC 80003, Sample 8G, 11 x 45;
12, x 50 RV
- 13, 15 *Sarsicytheridea macrolaminata* (Elofson), GSC 80004, Sample 8B, x 55 LV
- 14 *Sarsicytheridea macrolaminata* (Elofson), GSC 80005, Sample 8B, x 55 RV
- 16 *Eucythere argus* (Sars), GSC 80006, Sample 8E, x 75 LV
- 17, 18 *Eucythere argus* (Sars), Sample 8E, Specimen lost RV.

LV.....Left valve
RV.....Right valve

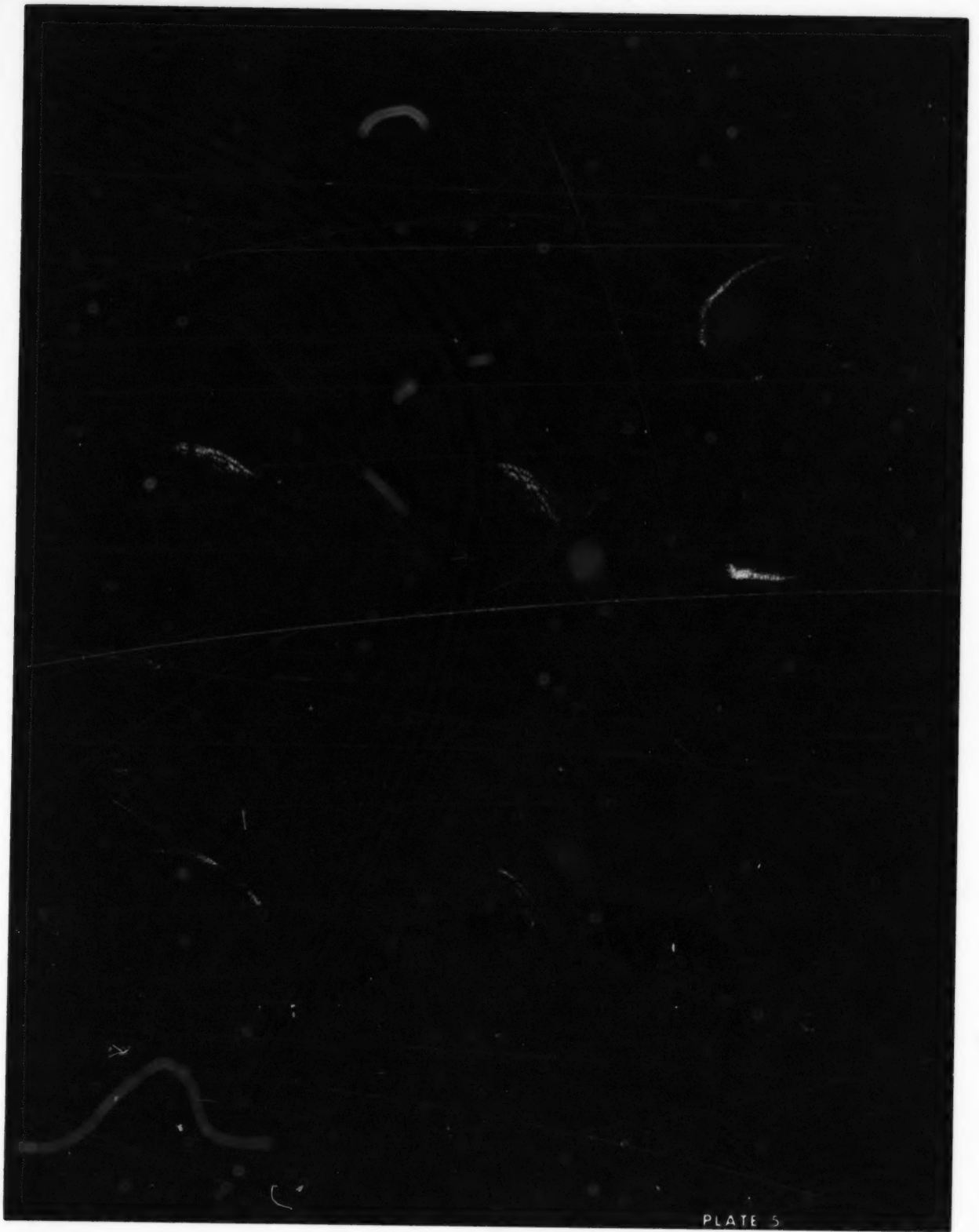


PLATE 5
(Scanning Electron Micrographs)

- 1 *Cytheropteron pseudomontrosiense* Whatley and Masson, GSC 80007,
Sample 26, x 90 LV
- 2, 3 *Cytheropteron pseudomontrosiense* Whatley and Masson, Sample 26,
Specimen lost RV
- 4, 6 *Cytheropteron champlainum* Cronin, GSC 80008, Sample 8B, x 70 LV
- 5 *Cytheropteron champlainum* Cronin, GSC 80009, Sample 8B, x 70 RV
- 7 *Cytheropteron inflatum* Brady, Crosskey and Robertson, GSC 80010,
Sample 8B, x 65 LV
- 8, 9 *Cytheropteron inflatum* Brady, Crosskey and Robertson, GSC 80011,
Sample 8B, x 65 RV
- 10 *Cytheropteron latissimum* (Norman), GSC 80012, Sample 8E, x 80 LV
- 11, 12 *Cytheropteron latissimum* (Norman), GSC 80013, Sample 8E, x 80 RV
- 13 *Cytheropteron nodosum* Brady, GSC 80014, Sample 8B, x 70 LV
- 14, 15 *Cytheropteron nodosum* Brady, GSC 80015, Sample 8B, x 70 RV
- 16 *Roundstonia globulifera* (Brady), GSC 80016, Sample 8E, x 90 LV
- 17, 18 *Sclerochilus contortus* (Norman), Sample 8C, Specimen lost LV

LV.....Left valve
RV.....Right valve



PLATE 5

PLATE 6
(Scanning Electron Micrographs)

- 1 **Cytheromorpha macchesneyi** (Brady and Crosskey), GSC 80017, Sample 7, x 70 LV
- 2, 3 **Cytheromorpha macchesneyi** (Brady and Crosskey), GSC 80018, Sample 7, x 70 RV
- 4, 6 **Cythere lutea** O.F. Muller, GSC 80019, Sample 8G 4, x 70; 6, x 75 LV
- 5 **Cythere lutea** O.F. Muller, GSC 80020, Sample 8G, x 70 RV
- 7, 8 **Cytheropteron nealei** Cronin, GSC 80021, Sample 8B 7, x 90; 8, x 95 LV
- 9 **Cytherura similis** Sars, Sample 8F, Specimen lost RV
- 10 **Cytheropteron arcuatum** Brady, Crosskey and Robertson, GSC 80022, Sample 21, x 70 LV
- 11 **Cytheropteron arcuatum** Brady, Crosskey and Robertson, Sample 21, Specimen lost RV
- 12 **Cytheropteron paralatissimum** Swain, Sample 22A, Specimen lost RV
- 13, 16 **Palmenella limicola** (Norman), GSC 80023, Sample 21, x 70 RV
- 14, 15 **Finnarchinella logani** (Brady and Crosskey), GSC 80024, Sample 8B, x 60 RV
- 17, 18 **Ilyocypris gibba** (Ramdohr), GSC 80025, Sample 4, x 50 LV

LV.....Left valve
RV.....Right valve